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Effective data compression model for on-line power system applications

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SUMMARY

The main objective of this paper is to develop an efficient data compression model for online power system applications such as load flow studies, state estimation, contingency analysis etc. and to calculate the round trip-time taken for sending the compressed data in client/server architecture. Martin Burtscher algorithm is used for data compression since most of the power system data is expressed in per unit representation which is in floating point format. Many research works have been reported for representing and solving power system problems in distributed environments which include RMI, Component based, SOA and Grid computing. As the size of power systems is growing larger and larger due to increase in demand and as the interconnections between large power systems may vary from time to time due to addition of new generating units and due to geographic conditions, it becomes difficult to estimate the current operating states of the real time electric power system networks and data communication between the networks becomes difficult. The proposed method of power system data compression finds faster rate of data communications where the data is required for real–time analysis in a distributed environment.

Key words: *data compression, on-line power system applications, power system data, distributed algorithms.*

1. INTRODUCTION

Effective power system operation requires power system engineers and operators to analyze vast amounts of information. In systems containing thousands of buses, the key challenge is to present this data in such a form that the user can assess the state of the system in an intuitive and quick manner. This is particularly true when trying to analyze relationships between actual network power flows, the scheduled power flows, and the capacity of the transmission system. With restructuring and the move towards having a single entity, such as an independent system operator or pool managing a much larger system, this need has become more crucial.

Deregulation has, and will continue to have, a tremendous impact on power system analysis and operations. In many regions deregulation has resulted in the creation of much larger markets under control of an independent system operator. This will result in even more buses and other devices for monitoring and control. Simultaneously, the entry of many new players into the market and the increase in power transfers will result in even more data to manage. Finally, system operators will come under an increased scrutiny since their decisions, such as whether to curtail particular transactions or not, can have a tremendous financial impact on market participants.

Similarly, power system networks are affected by faults, which gives rise to transients and disturbances across a network. Faults and events monitored by protection relays (with fault recording) and digital fault recorders installed on substation sites are stored as time-tagged records. The records contain information for fault analysis, assessment and adjustment of protection settings and, provided they can be rapidly retrieved from site, can be particularly useful when implementing control and operational decisions. A prime constraint of remote retrieval is the bandwidth limitation imposed by communications links. Records can be large (> *500* kilo bytes) and the communications link can present a 'bottleneck' if it is limited by bandwidth or peripheral modem speed. The problem is even more complex if site monitoring involves a number of recording units. As the demand for more data storage space and data transfer continues to grow at an unprecedented pace, the need for real-time data compression systems becomes more prominent. The essential criteria for compression are that the storage occupancy of the source data is sufficiently reduced such that the apparent integrity of the data is not adversely affected by the reduction method. By identifying redundancy in a data set, it is possible to reduce its effective size. In this paper, the compression of the power system model has been proposed for real on-line power system applications. Performance comparisons of the proposed method for network operation and control are also presented.

2. CURRENT TRENDS IN ON-LINE POWER SYSTEM ANALYSIS

The operational and commercial needs of the power industry required information systems to not only perform traditional functions but also support many of the new functions specially to meet the needs of competition with deregulation. The rapid development of the Internet and distributed object computing has opened the door for feasible and cost-effective solutions. The choice of distributed technologies such as RMI, EJB, CORBA and NET Remoting offers unique and powerful features such as zero client installation, on demand access and platform independence [1] for the design of the on-line power system analysis architecture. With the evolution and wide-spread deployment of the WWW accelerated by the rapid adoption of the browsers, web-based applications have been developed [2] for a variety of applications in power system simulations. Most of these applications use web techniques for information access and exchange. For example, Internet-based client-server concepts are used to monitor transmission substations [3] and an Internet-based energy trading system which allows buyers and sellers of energy to freely engage in trading activities over a wide range of energy source products and geographical regions has been introduced [4]. With the help of high performance CPU and fast network communication, more sophisticated applications have also been built on the web. Internet is widely used in a distributed environment to share data and resources for parallel computing power system applications [2]. An innovative application have been developed using Java [5] for the interactive learning of the power system stability on the Web. The remote power flow monitoring methodologies in a simulation environment has been introduced [6] and an educational tool for on-line power system analysis has been hosted in the Internet. A web-based system has been implemented to support electronic commerce solutions for deregulated electricity markets by re-engineering the legacy energy management system (EMS) software [7]. A web-based electricity market simulator has been introduced, which can be used as a decision-making tool for market participants [8]. In most of these cases, Java technology has been used for implementation. A prototype has been developed [9] for a distributed virtual reality system aimed at the training of operators working in power utility switching or distribution stations. It allows the user to exercise operations that typically consist of changing the topology of distribution networks by opening and closing the transmission lines, isolating equipments such as circuit breakers and transformers in order to perform maintenance or repair work, providing appropriate compensation or redistributing the load. Job training simulators based on client-server model with user interfaces have been developed for load dispatch [10]. A laboratory of interconnected power systems has been setup [11] providing students with a hands-on learning experience of the attributes and implications involved in the management and control of a small electric power system. It is desired to teach students how to analyze real-life, three-phase power system networks and show them the modern tools available to energy management system operators. One of the unique features of the EMS emulators is that they incorporate the emerging technologies of client-server and industry standard networking. Using advanced technologies along with readily available hardware and modern software programming techniques, a customized, graphics-intensive laboratory environment has been created. This environment enhances students' understanding of electric power systems and their performance by graphically modelling the active control elements of a power system. Most of the research works have been carried out within the development of training and educational tools for on-line power system analysis using modern and current trends of information technology. Models are essential to the operation and control of modern power systems. Models of on-line operations are typically more comprehensive than those used for power system planning. An on-line power system model has a relatively complex set of information, involving between *100* and *1000* different classes of information. Moreover, these models are closely tied to a distributed environment and loosely tied to a range of other information unrelated to power system computation throughout the utility. Creation, maintenance and verification of models are significant activities for most power system engineers. The desegregation of utility functions and the introduction of new power systems have increased the burden of model maintenance in a distributed environment. This introduces new problems of model information exchange, interoperability among power systems and exacerbates legacy issues such as version control and verification. In this context, it is worth revisiting the traditional modelling approaches to find improvements. To solve the problems associated with legacy power system applications, a data conversion model has been developed which represents the power system data in an XML form, which is a common solution required for making the power system applications interoperable in a distributed environment.

2.1 Client/server model

Conventional power system applications are, for the most part, self-contained monolithic programmes with limited access to one another’s procedures and data. They are usually cumbersome to build and expensive to maintain because simple functional changes require the entire program to be rewritten, recompiled and retested. By contrast, the client/server structure provides the scalability and robustness required to support mission critical power system applications such as: load flow monitoring, economic load dispatch and on-line dynamic security analysis. This clean, modern architecture which is server-based and database-driven is ideally suited for a web-based power system analysis. An important aspect of implementing a client/server power system application refers to the distribution of different parts of the power system application between the client and the server, and rendering this implementation transparent to the power system client which is located at a geographically different location. The main advantage of the two-tier model is better reuse, namely, the power system application logic is placed solely on the server and can be initiated from many power system clients. The client/server model has practical drawbacks that often outweigh its economic advantages. Developing client/ server programmes is three times more expensive than developing traditional power system applications. It is more difficult to program a distributed application that has a richer set of error and failure modes than a centralized one. Another problem is that many applications do not easily decompose into pieces that can run on separate machines connected by a relatively slow (compared to memory speeds) communication medium. Any upgrade requiring replacement of the client's machines is cost-prohibitive.

2.2 Multi-tier architectural model

A three-tier architectural model for power system applications containing a service tier, data store tier and Man Machine Interface (MMI) has been proposed and shown in Figure 1. To overcome the limitations of the two-tier architecture, a middle logical tier has been added between the presentation tier and the data tier. This is where the power system application logic resides and performs a number of different operations. The middle tier can be physically located on a separate machine but this is not always necessary.

In a power system application where the amount of clients is limited, the power system application server can be deployed on the client's machines or on the database server, thus reducing the number of interface connections required and making the system faster. As the number of power system's clients grow, the middle tier can be moved onto a separate machine which addresses the desired scalability benefits.

The benefits of the three-tier model are as follows:

* ***Scalability***: In this model the application servers (i.e. power system application logic) can be deployed on many machines. The database server no longer needs connections to every client. Instead, it needs to be connected with a fewer amount of application servers.

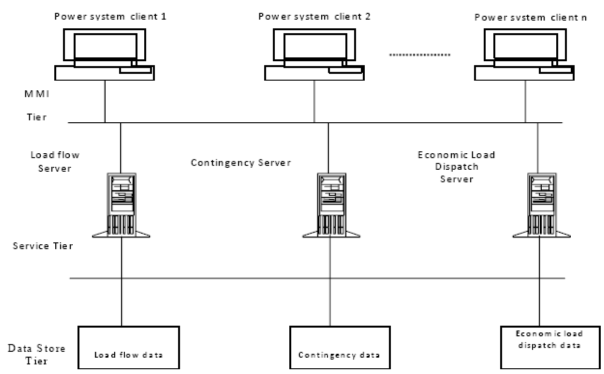

Fig. 1 Three-tier client/server architecture for power system application

* ***Data Integrity***: Since all database updates pass through the middle tier, the middle tier can ensure that only valid data is allowed to be updated in the database, thus removing the risk of power system data corruption.
* ***Security***: Security is implemented on multiple levels thus making more difficult for a client to access unauthorized data than it would be if security was placed only on the database. Power system application logic is implemented on a more secure central server, which is safer than being distributed across the network.
* ***Reduced Distribution***: Potential changes in the power system server application can be centralized into one place.

Power system communication internetworking, such as the interconnection of multiple independent utility systems has become the norm in on-line power system analysis. With rapid development of broadband techniques LAN-based power system operations can be extended to large complex power systems to perform a certain degree of web-based power system operation and control.

2.3 Web-based simulations of power systems

The Internet is basically a system allowing computers to communicate with each other. With computers diminishing in both size and price there is a tremendous growth in the number of computers used. As they became widespread, new ways to harness their potential are constantly being developed. Smaller, yet more powerful, computers are linked together to share memory space, software and information. A silent shift to distributed computing is happening. Today, computer systems are being implemented as clusters of servers sharing the workload and supporting each other in various environments.

Many services running on different platforms are converging to use the Internet as a common medium of interaction between humans, between human and machine, as well as between machines themselves. Traditional Internet functions of sharing news, providing entertainment, educational and documentary information are gradually being replaced with commercial, banking and financial transactions, as well as other everyday services such as telephone and television broadcasts over the Internet. Industrial services including process monitoring, real-time control and automation are also being developed for the Internet.

Clean, inexpensive, transportable electricity is an indispensable commodity of modern civilization. But the electric supply network is probably the largest and most complex man-made infrastructure in the world. Therefore many analyses are needed before any operations can be performed on the actual network. There are many possible phenomena in power systems, and they all need to be carefully analyzed with different simulation techniques.

The existing power system simulation designs are very similar to those designed for the mainframe computers of many years ago, such that different simulation analyses are usually lumped together in a single package and are normally designed for a specific platform. However, the operational and commercial needs of the power industry require information systems to not only perform traditional functions, but also support many of the new functions especially to meet the needs of competition with deregulation.

The rapid development of the Internet and distributed computing have opened the door for feasible and cost-effective solutions. The Internet, being platform independent, allows users to continue using the platforms with which they are most familiar. In addition, the heterogeneous operating environment provided by the Internet helps to achieve continuous development of distributed applications by integrating different kinds of computer hardware and software systems.

2.3.1 Web-based power system simulator - Design and implementation

The web-based power system simulation architecture has been developed [2] using a three-tier client/server architecture as shown in Figure 2. The first step in designing a web-based power system simulation environment is to define its functions. The power system simulation functions are creating and editing of the power system networks and the execution of various simulation analyses. The support for each function will span across multiple tiers with components responsible for specific roles. The motivation behind this design is to minimize software coding efforts by reusing many of the existing simulation routines.

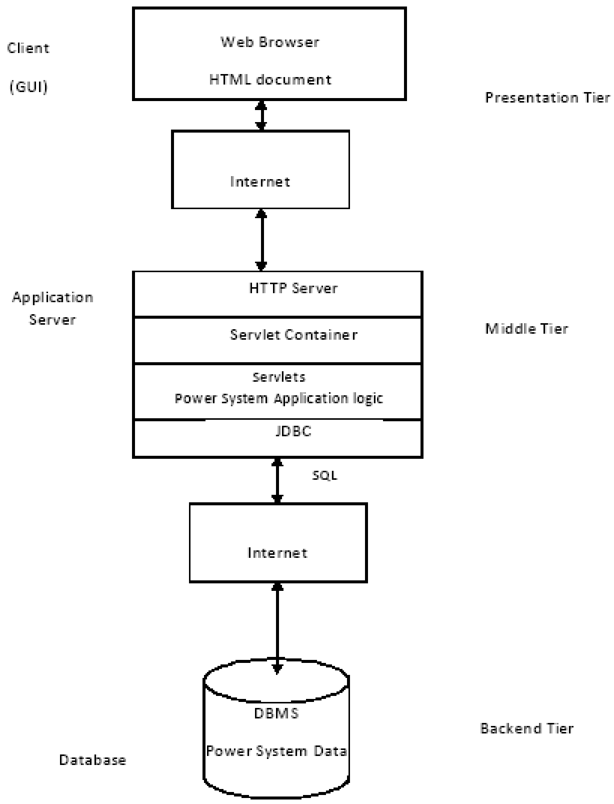

Fig. 2 Three-tier architecture for web-based power system simulation

The power system application logic is separated from the GUI and the backend database, so that changing any of the layers can be done without the need to change other layers. The top layer is the presentation layer, where the client machine is located. Data are presented by a thin client solution, using a web browser and the HTML standard file format. The parameters of the application are controlled by the client side using HTML forms. The user sets the parameters and then activates the process on the server side via the network.

All the power system client sees is an abstract operation request which takes input and output parameters. Since web browsers are available for almost all platforms, using them as GUI eliminates the need for designing different application interfaces across different platforms, and also allows an adequate presentation of the application to the user without too much coding effort. The middle layer is the application server, which implements the power system application logic to process data requests. An HTTP web server is running on the machine to receive HTTP request from power system clients, and send HTTP response back to the clients.

The main control logic is encapsulated at the server side through Java servlets, which represent different modules of the application. The use of modular design enables modifications and enhanced features to be added easily to the system to properly respond to specific requirements of the user. The back-end layer is a database that stores and manipulates the power system data at the back-end. The connectivity to the database from the middle layer is enabled through the JDBC drivers; this allows the power system application logic to be written with little dependency on the type of the database used. In addition to the databases, the information service and legacy systems also comprise all the components necessary for undertaking the various types of power system simulations. Once the user fills the necessary power system data in the HTML form and clicks the Submit button, the request to a Java servlet is posted. The servlet reads the input data and performs the power system computations, using at the same time JDBC to communicate with a database to obtain the power system data; the dynamic response is then generated and given back to the client for display, depending on the user's inputs. With the advent of the above-mentioned web-based power system simulator, load flow simulation, short circuit fault analysis and harmonic penetration analysis have been carried out successfully [2]. This simulator has a serious drawback of not having common format for interchanging power system data between tiers.

2.4 Power system data representation

Effective power system operation requires power system engineers and operators to analyze a vast amount of information. In systems containing thousands of buses, the key challenge is to present the power system data in a form such that the user can assess the state of the system in an intuitive and quick manner. This is particularly true when trying to analyze the relationships between actual network power flows, the scheduled power flows and the capacity of the transmission system. The lack of a reliable, simple and universally deployed power system data exchange format has long limited the effective communication between heterogeneous on-line power system operations.

The need for a centralized means of managing power system data has become evident as the role of computers in power system operation and planning continues to evolve. Two decades before, a database management system was developed to support a major electric utility's operating and planning information requirements [12]. Its structure was of the relational type, extended to suit the relationship of the rcords commonly found in power system applications. The power system database management system developed by Schwab is a software package consisting of programs for defining, accessing, modifying, listing and saving a database.

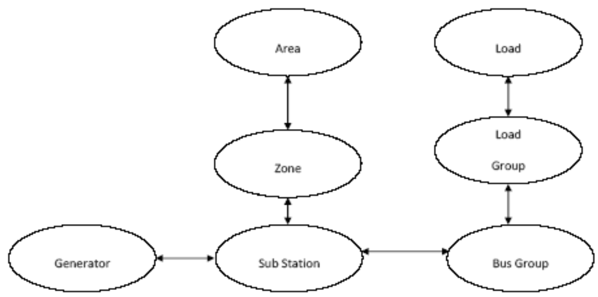

Fig. 3 Logical database for power system planning and operation programmes

It also maintains subroutines and programmes for predefining access requirements and for accessing the physical database. The database management function can be viewed as the central energy control system. In a relational structure of this kind, power system data are logically arranged as a collection of two dimensional arrays. Each data array is called a data type. A data type represents a distinctive group of data such as a set of meter readings, a complete description of transformers, generator data etc. The commonality of data requirements between power system planning and operation functions is shown in Figure 3 which illustrates the logical database design diagram.

Modelling of on-line power systems is an area of ongoing interest in the transmission management and control systems community in a distributed environment. Continuing development is driven by two forces. The traditional tasks of model maintenance and management must be achieved with fewer resources. At the same time, co-ordination and information exchange between the models have become a priority. The former force arises from the disaggregation of subsystems in a power system and the introduction of new power systems. The traditional architecture faces the problems of versioning and version control, migration of models between different schemas, the transformation of models for different purposes or any change in power system logic and merging of old power systems with an existing power system model from different sources. These tasks are handled by semi-manual methods or heavily customized software.

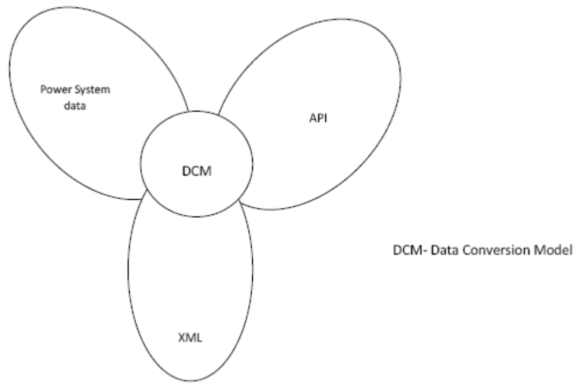

Fig. 4 Bringing together power system data, API and XML for solving legacy issues

Data conversion model is the one which converts any form of power system data into a well-formed representation of power system data which minimizes the overheads associated with the data transformation between different power systems and provides a global format for power system data. Conversion of power system data into an XML form enables the independency of the data used by a power system application. The proposed data conversion model is a standards - based integration platform designed to significantly reduce the engineering efforts required to integrate power system data in the distributed environment; as shown in Figure 4.

Legacy power system applications represent power system data as a set of flat tags in a flat file or in a database. In order to access the data, the power system application server must know the tag name for each data value it accesses. Each power system has typically developed its own proprietary tag naming conventions to add some context to the arcane tag names, thus externally providing meaning to a particular data element. The tag name conventions are unique to individual power system in a network. The power system application that needs this data must either be programmed to understand the proprietary tags or must use separate data transformation tools that transform the data for each power system application.

As a power system changes over time due to new data points being added, the data moving from the power system's client to the power system's server have to be updated. The data transformation mapping must be continuously maintained to reflect the changes in the underlying power system application server programming. With a common model-driven approach, applications exchange data in the context of a data-conversion model that hides the details of how data are stored internally in an individual power system client. The use of data conversion model allows individual power system not having to maintain proprietary, arcane tags-naming conventions or not having to send the data in one particular order. The proposed data conversion model makes the legacy power system data customizable to the existing power system application. Figure 5 shows the hierarchy of power system data access in an XML form by the legacy power system clients.

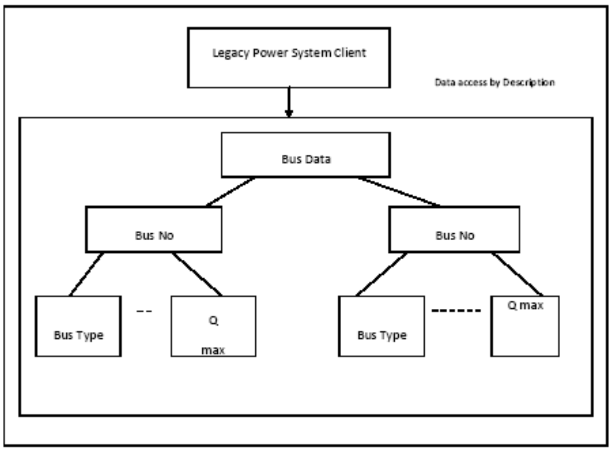

Fig. 5 Hierarchy of the power system data access through data conversion model

3. DATA COMPRESSION AND DECOMPRESSION MODEL FOR ON-LINE POWER SYSTEM APPLICATIONS

The legacy power systems data of floating point format, dealt in per unit format, and recent power system data are in XML form. A data compression and decompression model has been developed to compress this huge amount of data efficiently and send the data over a network in a minimum time span. Data compression techniques can be both with loss and lossless. Since most of the power system data representation is in the floating point number format, it would be better to adopt lossless data compression techniques. Lossless data compression methods are widely used to reduce data overhead in storage systems. Many data compression algorithms and hardware implementation architectures have been proposed in the past decade. Huffman coding, arithmetic coding, Lempel-Ziv (LZ), and Lempel-Ziv-Welch (LZW) are some of the lossless compression algorithms commonly in use today. LZW is a dictionary-based data compression that compresses content character by character; these characters are combined to form a string. A special code is assigned to new strings and the strings are added to the dictionary. Thereafter, when the string is repeated, it can be referred to with that code. The LZW algorithm requires a sequential construction of the dictionary and involves extensive comparison of input data with the dictionary content during compression.

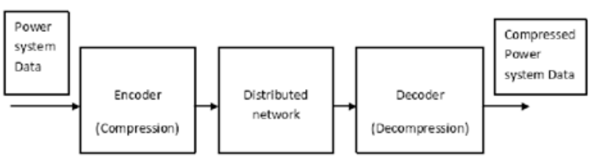

Fig. 6 Power system data compression

Figure 6 illustrates the power system data compression process whereby the input data is compressed, stored or sent through a network to another location, where it is decompressed and the output data is obtained. The proposed compression and decompression model has been implemented in RMI-based online Load flow monitoring in a distributed environment. These power system clients are interconnected with a load flow server, shown in Figure 7 [13]. A client computer basically does the distributed power system monitoring through an applet for every specific period of time and frequently exchanges data with the server. In the client program, the data is read from an input file, stored in a double array and converted into binary form. The data are then submitted to compression which is carried out by xoring the value with the most common predicted value and compressing with leading zeros.

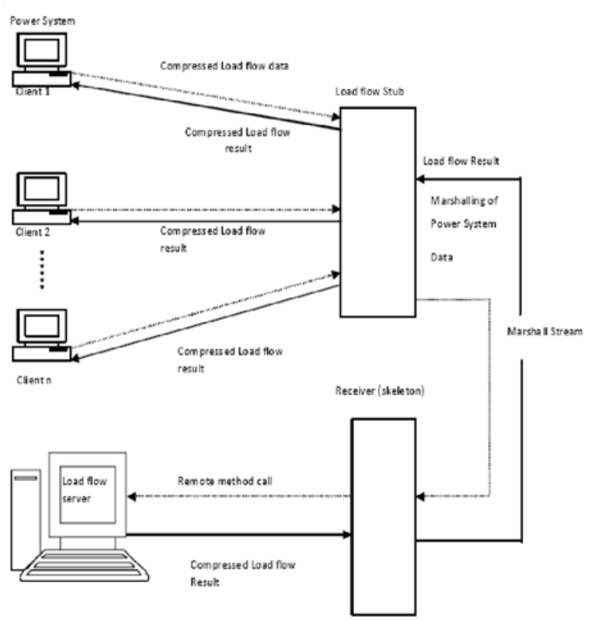

Fig. 7 RMI-based Load flow compression and decompression model

The compressed data are received from the client by the load flow server which decompresses it. The server does the load flow computation and then distributes the results in a compressed form. Chronologically, the server process should be started first so that it can take the initiative to set up a connection link. It then starts waiting till it receives a connection request from the client. A client can register itself with the remote object (server object) just by invoking the registration procedure on the server object, when it needs a service from it. The remote object obtains the necessary data from the registered client objects and responds back to them respectively with the results. This total process can be automated by making the server get the input data for every specific period of time. Transaction of data between clients and server takes place several times and so the possibilities of the occurrence of errors may be high. Hence it must be handled properly.

4. DATA COMPRESSION ALGORITHM FOR A RMI-BASED LOAD FLOW MONITORING

When a remote client object registers with a remote load flow server object, the server uses the remote client reference to invoke its method and obtain the system data from thet client and then provides the service through its methods. Both client and server objects are considered as remote objects and, hence, an inter-remote object communication is achieved. The server object uses a single thread of control to distribute the load flow results simultaneously to the clients registered with it. Subsequently, the following steps are to be carried out:

i. Start load flow server.
ii. The server should invoke its own registry service.
iii. Register a load flow client's and load a server's stub dynamically from a common location.
iv. Load flow server uses the load flow client's reference to periodically receive the compressed load flow data from the power system's client.
v. The server un-compresses the power system data, computes the load flow and returns it to the client.
vi. The client obtains the result through a load flow stub.
vii. For every specific period of time, the server automatically receives system compressed data from the client, thereby providing automatic load flow requirement evaluation.

5. RESULTS

The aforementioned compression/decompression algorithm has been implemented in Windows XP-based HP workstations connected in an ethernet LAN. The major factor influencing the performance of the proposed model is the round trip time (RTT) that includes the convergence time. The round trip time measures the time needed from the point when the power system client initiates a method invocation to the point when the client receives the results. The round trip time is measured for all the power system clients that have invoked the load flow method simultaneously without any delay. The performance analysis of the proposed data compression model has been carried out with and without compression of various power system data. The variations of round trip time with respect to the number of buses are shown in Figure 8. From the above graph it is evident that as data size of compressed and uncompressed data for small power systems is almost similar and hence their RTTs are also similar.

As the size of the power system data and number of power system clients increases, compressed data occupies more bandwidth than uncompressed data. Hence the RTT also differs more. From the above graph, it is very much evident that data compression algorithm performs better then the conventional distributed RMI model for load flow monitoring.

6. CONCLUSION

An effective RMI-based distributed model has been developed to compress power system data, send the compressed data across a network, decompress it and retrieve the data and calculate the round – trip time taken for the process in a single server – single client environment. Attemps have been made to overcome the overheads associated with data congestion through this model. Although, data communication models are well established, this paper emphasises a unique methodology based on RMI to serve a large number of clients in a distributed environment which enables less congestion for data flow. The time taken to send compressed data will be less, the networks will not be jammed and the whole process of data transfer will be more efficient. A practical implementation of this approach suggested in this paper was assessed based on RMI based load flow monitoring but it finds major online power system applications such as contingency analysis, economic load dispatch, Unit commitment etc. Accordingly, the proposed model can be implemented for power system network spread over geographically.

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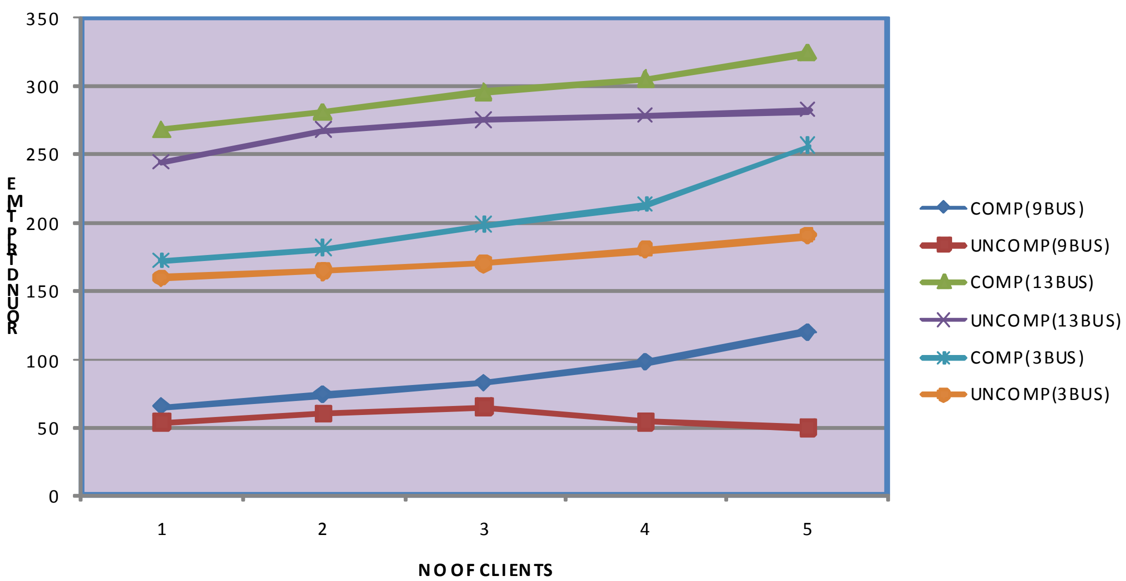

Fig. 8 RMI-based load flow compression and decompression model

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UČINKOVITI MODEL KOMPRESIJE PODATAKA ZA RAČUNALNE APLIKACIJE ELEKTROENERGETSKIH SUSTAVA KOJE RAZMJENJUJU PODATKE U STVARNOM VREMENU

SAŽETAK

Osnovni cilj ovoga rada je razviti učinkovit model kompresije podataka za računalne aplikacije energetskih sustava kao što su analiza protoka informacija (load flow studies), proračun procjene stanja energetske mreže, analiza sigurnosti, itd., koje razmjenjuju podatke u stvarnom vremenu, te izračunati povratno vrijeme potrebno za razmjenu komprimiranih podataka u arhitekturi korisnik/poslužitelj. U tu svrhu korišten je Martin Burtscherov algoritam za kompresiju podataka budući da je većina podataka energetskih sustava izražena po jedinici zapisanoj u formatu pokretnog zareza. Mnogi radovi su se dosad bavili rješavanjem problema energetskih sustava u paradigmama distribuiranog računarstva kao što su RMI, Component Based, SOA i Grid Computing. Budući da elektroenergetski sustavi postaju sve veći i veći zbog povećane potražnje za energijom te da povezanost među sustavima može varirati s vremena na vrijeme, kako zbog dodavanja novih jedinica za proizvodnju energije tako i zbog zemljopisnih uvjeta, postaje sve teže procijeniti aktualno stanje elektroenergetskih mreža, a podatkovna razmjena postaje otežana. Predložena metoda kompresije podataka elektroenergetskih sustava nudi brzu komunikaciju podataka gdje su podaci, potrebni za analizu u stvarnom vremenu, u okruženju distribuiranog računarstva.

Ključne riječi: *kompresija podataka, računalne aplikacije energetskih sustava, podaci energetskih sustava, distribuirani algoritmi.*