SAGE ARCHITECTURE FOR POWER SYSTEM COMPETITIVE ENVIRONMENTS

Antonio Joaquim S.R. Silva **Ayru L. Oliveira Filho** **Luiz A. Cordeiro Pereira** **Luiz Correa Lima**

Nivaldo Lambert **Maria Fernanda P. Amorim** **Gilberto P. Azevedo**

CEPEL - Centro de Pesquisas de Energia Elétrica
Brazil

Abstract: The Brazilian power sector restructuring points to a new energy market model that is expected to come into operation at the second half of the 1998. This paper presents a computational architecture that creates the ambience necessary for the integration of new functions to support the requirements of control centers in this new scenario. The proposed architecture increases the availability of data at the different departments of a company, providing the information needed to reach right decisions.

Keywords: Open Access, Control Center, Independent System Operator, Distributed Systems, SCADA, EMS.

1. Introduction

Nowadays, a mandatory requirement for a supervisory system specification is the selective and secure diffusion of informative data from the control center. It will become even more important when the changes in the playing role of the power companies take place in the new scenario.

In this near competitive environment [1] those competitors whose control center is better equipped will be in a clearly advantageous position. The new market player must get detailed, up-to-date and precise information about the system in order to manage it efficiently and economically.

SAGE - Open Energy Management System (**S**istema **A**berto de **G**erenciamento de **E**nergia, in Portuguese), developed by CEPEL, is an integration of advanced computational technologies aimed at providing a significant contribution for the new control centers conception.

Advanced new applications can be built straightforward on top of SAGE’s framework besides the conventional functions in the power system control center. An architecture that integrates the relevant data in the company can bring significant benefits for both on-line operation and several other decision-making activities. The application of SAGE will bring new levels of speed in the transactions performed in the new competitive and deregulated market environment.

In the foreseeable future there will be a great number of functions inside SAGE concerned to Optimization, Network Analysis and Symbolic Processing. They will enhance the quality of the relevant data available at the control center (and in the whole utility), and will also provide new advanced tools for improving the operation.

(*) CEPEL - Centro de Pesquisas de Energia Elétrica
Caixa Postal: 68.007 CEP: 21.944-970
Rio de Janeiro - Brazil
Tel.: (+55+21)598-2134 Fax: (+55+21)260-1340/260-6211
e-mail: ajs@fund.cepel.br

2. SAGE Overview

SAGE was created for providing a technological upgrade for conventional control and supervisory systems, besides solving several problems concerned to them:

- Software and hardware manufacturer dependency;
- Ever increasing maintenance costs due to software and hardware early obsolescence;
- A too diversified SCADA/EMS system requires an expensive experts team, without scale benefits;
- Difficulties for integrating new applications.

The major guideline in SAGE development was the use of standards for open systems [3][4]. This guarantees portability, interconnectivity, and interoperability. SAGE technological basis assembles several internationally accepted standards.

SAGE's basic real time modules are organized around a high performance real time database, which provides communication and synchronization among them.

SAGE also provides a non-real time database that supports applications for analysis, statistical survey, forecasts, simulation, and several other helpful functions that will become essential in the new electric system environment.

SAGE's major functional characteristics include:

- Distributed real time database with selected replication;
- Distributed configuration management that allows control processes, failover, and balanced processing charge;
- Large SCADA protocols library for communication with Remote Terminal Units (RTU) and other control centers;
- Gateway for real-time SCADA with competence for data redistribution to other control centers;
- Easy integration between real-time and the corporate databases;
- Custom built human-machine interface;
- Alarm filtering;
- Network analysis functions providing diagnosis and ancillary data for the dispatcher;
- Automatic Generation Control (AGC).

Some of SAGE's new subjects are artificial intelligent applications for power system restoration [5], whose prototype has already been integrated into SAGE, and power system alarms diagnosis [6].

Several SAGE installations have been successfully put into on-line operation. ESCELSA, C. F. L. Cataguazes Leopoldina, ELETROSUL, CHESF and FURNAS use SAGE for their local operation center, regional operation center, and distribution operation center. During 1998 SAGE will be installed both at the system operation center at CHESF and ELETRONORTE and ELETROBRAS' national operation center in Brasilia.

3. Brazilian Electric Power Restructuring

When the initial stage of the Brazilian power sector restructuring is completed, the power market will be based on the following items: competition in the generation process, a neutral transmission grid and an Independent System Operator (ISO). The main target of the new trading model is to create the wholesale energy market. This market will replace the present system of regulated generation prices and renewable supply contracts.

The key features of the new Energy Market (EM) described by the Brazilian Power Sector Restructuring Project are summarized below:

- The ISO, jointly owned by the sector agents, will be responsible for operational planning, scheduling and dispatch. To carry out these functions it will receive data on water inflows, reservoir levels, plant availability and fuel costs. Based on this information the ISO will plan system operations on successively shorter time periods, ensuring hydro-thermal optimization through the use of procedures that are similar to those now in place;
- In the final stage of operational planning, the ISO calculates a price which represents the system marginal cost at which supply and demand are in balance. This spot price will only be defined by a functioning competitive market;
- Generation companies, the public service distribution and retail companies will continue to trade most of their energy under bilateral contracts that will specify contract prices and fixed volumes for their entire duration. The purpose of these contracts will be to protect the parties against exposure to the risk of the potentially volatile spot EM energy price;

A set of Initial Contracts will be settled to initiate the Energy Market in an orderly fashion. The duration of the Initial Contracts will be eight years. Contracted volumes will be constant in the first four years but will then decline gradually.

4. New Functions Required

The integration of new functions into existing control centers for assisting the adequate operation of the new scenario is an identified necessity. However, the clear definition of which functions will be required depends on the peculiarities of each market agent. In this work, we will focus on the following agents: Independent System Operator (ISO), Power Exchange, Generation Companies and the Open Access Same Time Information System (OASIS).

4.1 ISO

The ISO plays a central role in the new environment: it is responsible for the system operation. It receives the next-day generation merit order from the Power Exchange and verifies if this dispatch is feasible taking into account the restrictions in the transmission system. The differences from the planned dispatch, implemented by the ISO for keeping the system reliability, are sent back to the Power Exchange for credit or debit. The main ISO responsibilities, which will be supported by an EMS environment, are described in [9]:

- Coordinate the day-ahead scheduling and real-time balancing on behalf of all users of the grid;
- Control the operation of the transmission system of the participating utilities;
- Provide, in a transparent manner, open access to the transmission grid and ancillary services to all users;
- Manage the congestion and constraints of the transmission system in a way that all the users are subject to the same procedures and prices;
- Procure ancillary services on a competitive and unbundled basis and offer them to users as unbundled services, where possible;
- Execute settlement functions;
- Provide a transparent information flow.

The basic EMS functions (Network Modeling, State Estimator and Contingency Analysis) will not be changed in the new system model. In addition, new programs should be implemented to cope with the new challenges. For the ISO, the most important one is the Available Transmission Capacity (ATC) real-time calculation program. The ATC calculation can be carried out by an Optimum Power Flow program. Nevertheless, this static calculation should be validated taking into account dynamic aspects. This can be accomplished with the incorporation of Voltage Security Assessment (VSA) and Dynamic Security Assessment (DSA) procedures.

The ATC values are sent to the Power Exchange (through OASIS) and have a fundamental role in the decision-making process of the market agents.

Other necessary functions for ISO environment are the Transmission Access Costing calculation and the Transmission Congestion Costing calculation.

4.2 Power Exchange

This agent acts as an electronic marketplace for power transactions. It is responsible for the following duties:

- Receive the day-ahead bids sent by generators, and rank them in merit order;
- Receive the power transaction orders from the market agents. In the hour-based market, these transactions make possible the establishment of the spot price;
- Receive the ancillary service transaction orders (frequency control, voltage control, etc.)
- Execute the market daily accounting;
- Send the day-ahead scheduling plan and the spot market transactions for execution by the ISO;
- Receive the differences from the scheduling plan, executed by the ISO in order to handle the real-time unforeseen system conditions;
- Distribute the ATC information and the differences from the scheduling plan, received from the ISO, to market agents.

The information exchange environment is supported by OASIS. In terms of new applications, the Power Exchange will need a special financial package in order to cope with the new market commodities: energy and services.

4.3 Generation Companies

In the new market the generation companies are organized in small units so that no single unit has market power. Generators can supply capacity, energy and ancillary services like spinning reserve, voltage control, frequency control, black-start capacity, etc.

The generation companies control centers should have tools for optimal scheduling including the units maintenance program. These tools should also take into account the current and expected values of spot prices [1].

The generation units should be ranked in terms of profitability based on revenues calculated on the basis of spot prices, at the generation bus [9]. This rank should be take into account by Optimal Scheduling package.

4.4 OASIS

The OASIS operates as a bulletin board for the power market. The system grants open access to the relevant information that is the basis of decision making process for the market agents. Internet is the media used for information diffusion.

In terms of architecture this agent has the following requirements [10].

- Flexibility - in order to permit the integration of new functions in an easy fashion as required by market evolution;
- Expandability - in order to permit the OASIS system expansion as new agents reach the market with new performance paradigms;
- Interoperability - the market agents should be able to communicate each other utilizing the available functions in their original computational systems.
- Security - information should circulate with the necessary security for guaranteeing the non interference of any external agent;
- Nondiscriminatory Access - all users must have opportunity to access the required information. Any additional functionality or performance requisite should be offered at reasonable fees.

Another requisite is the utilization of tools, languages and standards available in the Internet environment.

5. SAGE Architectural Support for the New Environment

At the ISO and Regional Company levels there is a clear need for evolution of the information handling facilities available at the Control Center. This comes from the evolving nature of the information (from acquisition-based to optimization and transaction-based) as well as its quality requirements (accuracy, timeliness, ease of exchange, etc.). In a deregulated environment, information can be considered not only as a resource aimed at reliability issues, but also related to the possibility of profit/losses. At the computational level this need can be translated into a mandatory move to an evolutionary computer architecture for the majority of existing control centers, which still present old-generation infrastructure.

SAGE incorporates an open evolutionary architecture designed to bring to control centers the ability to easily incorporate new functions, satisfying this way the requirements of the new scenario. In the following paragraphs we present some considerations about the requirements posed to infrastructure in the new environment and how SAGE makes provision for handling those requirements.

5.1 Integration Easiness

SAGE provides two specific environments for application integration in the control center.

The first environment is directed to time-critical applications supported by a high-performance distributed real-time database. This is the case of SCADA functions and other functions that perform data transactions directly with the SCADA system (Generation Rescheduling, etc.). This environment is suitable for the integration of traditional high level applications like Network Analysis functions (State Estimation, Network Configuration, Contingency Analysis) and AGC, as well as Operator Assistance Tools (like Emergency Control). New emerging tools aimed at improving operation reliability through dynamic assessment of system state (Voltage Security Assessment, Transient Security Assessment) also belong to this environment. In addition, this is the environment of choice for the ATC function needed in the new model of the power industry. Basically, the infrastructure comprises a set of interfaces to utility libraries aimed at simplifying the extra coding or modifications of existing code when integrating a new application. Those libraries provide functions for database access, event notification, alarm generation, logging, exception handling and process control.

The second environment is directed to non-time-critical applications supported by any commercial relational database server. This environment is suitable for the integration of quasi-real-time functions that explore the import/export capability of SAGE, for obtaining access to real-time data in an off-line environment. In addition to those there are off-line functions like Network Analysis Study Mode and Post-Operation Analysis functions, as well as planning functions. In the new sector model this environment will have to support a number of financial applications, many of them probably built from components available off-the-shelf. This environment can be characterized by application development and integration based on the availability of information in a relational database server. Rapid Application Development (RAD) tools and toolkits can be typically used. Visual languages and tools and GUI builders are highly adequate for this environment. Web-based interfaces, with pages formatted in HTML or Java/JavaScript can be foreseen as a very useful and even mandatory resource. This environment also promotes the integration of information present in the Control Center with information stored in corporate databases. This is the environment of choice for integration of applications related to the role of a Control Center as a Power Exchange or OASIS Provider.

5.2 Advanced Communication Architecture

The new described scenario shows a very clear situation where the computational systems used by the ISO, OASIS, EM and other agents, have as a fundamental requirement a very high interoperability capacity on the data links established with other control centers and power plant equipment used on supervisory, control and automation of the electric system.

This required interoperability may be accomplished with the availability of a large number of SCADA/EMS application protocols (used on the three top levels of the Open Systems Interconnection model), combined with a variety of transport protocol stacks (used on the four bottom levels of the Open Systems Interconnection model), and with a user friendly configuration tool for giving to the end user the ability to select desired protocols without the need of software development activities.

Based on this view, the development of the Communication and SCADA Subsystem (SCD) on SAGE was built over architectural guide lines that makes possible to the user to configure all of the needed computational and communication support using the same power plant modeling and configuration tools. This configuration task includes parameters like channels and interfaces used in the links with other Control Centers and RTUs, application protocols and transport protocols supported on that links, computer nodes of the configuration, failover strategy, etc.

The implemented architecture covers the application and upper levels (1) open protocols based on international standards IEC/870-5-xx and IEC/870-6-xx, like ICCP6.0, DNP3.0, IEC/870-5-101; (2) integral proprietary protocols, like Leeds & Northrup C3000 and Westinghouse Redac-70; (3) proprietary protocols based on international standards, like Foxboro LN/Tc57; (4) the Brazilian standard SINSC protocol, published by ELETROBRAS and used by all utilities on the SINSC network, and, on the transport and lower levels standards like X25, TCP-IP (including PPP) and IEC/870-5-1/-2.

Figure 1 shows the architecture implementation where application and upper level protocols are controlled by Protocol Converter clients and lower level stacks resides locally in Transport Servers, Device Drivers for intelligent communication modules, Frame Firmware modules and can be remotely accessed by TCP-IP socket connections.

The very clear separation between protocol conversion tasks and protocol transport tasks implemented in SAGE provided some solutions that are practical examples of the importance of a flexible open architecture. Two interesting examples are presented next.

- At C.F.L.Cataguazes-Leopoldina, SAGE is connected to the power system via RTUs at the distribution control center level. The regional centers are connected to the SAGE's system operating center using TELEMIG X25 public network (MinasPAC). RTUs use LN/Tc57 protocol transported on X28 connections with the network. SAGE on regional control centers uses, for the connection with each RTU, one X25 permanent virtual circuit (PVC) transporting the IEC/870-5-1 FT3 frames of LN/Tc57, and two PVCs transporting the application level of IEC/870-5-101 protocol in the connection with main control center.
- At ELETROBRAS' National Control Center (CNOS) the use of only one protocol at the application level (SINSC protocol) and only one protocol on lower stack (X25/X75) required specific software development at the utilities' control centers to allow a secure connection. Now, using SAGE, the use of standard protocols can help those utilities to establish their connections using open software available on most actual systems.

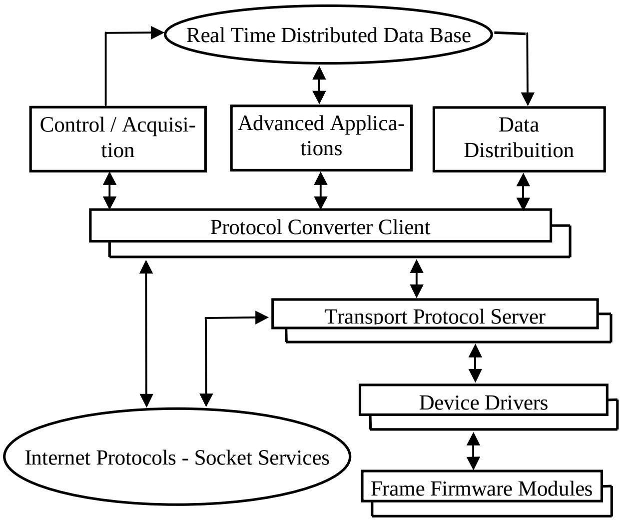

Figure 1: Communication architecture

5.3 Processing Capacity

The new on-line tools that are being identified as part of an EMS will demand a greater processing capacity from the computer architecture available in control centers. Depending on the support hardware installed it may be difficult to expand the computational power to match the foreseen increase of processing load.

The integration of extra computational resources in SAGE is simplified. The transport and presentation level standards that was adopted make it possible to add new computers to the real-time network without changing the running system. In this way, one can increase the computational power on demand by attaching the appropriate machine even if it is from a different manufacturer or of different technology (e.g. parallel machines).

If we consider the use of parallel processing over a distributed architecture like those present in modern control centers, there are some techniques to explore the available resources by applications running in a distributed way.

The MPI (Message Passing Interface) system, an evolution of PVM (Parallel Virtual Machine), provides communication and synchronization operations to be used in parallel applications running over a distributed memory architecture. MPI represents the present standard in message passing interface and is available for a wide range of computer platforms.

The system can be used apart from the SCADA/EMS real-time data subsystem. As it is a basic communication software based on message passing, efficient parallel applications can be written using MPI. The drawback here is the complexity added to programs, since the developer needs to deal with communication, synchronization and performance issues.

Another emerging standard for parallel programming is HPF (High Performance FORTRAN). This programming language is based on FORTRAN 90 and is well suited for data parallelism (the same task working on different portions of data). HPF makes easier to work with vector and matrices that can be partitioned and distributed over several computers on the network. As there exists HPF implementations over MPI libraries, this alternative can be used with very low impact over the control center computer environment.

As a third option, the Distributed Shared Memory (DSM) systems can be considered. These systems simulate a shared memory over a distributed architecture. The main advantage of this approach is the easy of programming, since all process communication and synchronization is done through readings and writings to the shared memory.

All the described techniques for parallel processing can be used in SAGE. In fact, SAGE's real-time database is actually implemented over a DSM support. The applications communicate with themselves through the writing to shared memory areas that can be replicated in some or all real-time network sites. Synchronization primitives are also available.

5.4 Secure Access

One of the greatest challenges faced by a modern control center corresponds to the security issues raised when connection to the Internet is considered. The huge benefits of being connected to a widely available network like the Internet are quite obvious these days, but what must be considered is how to provide access to the control center in a well-mannered and controlled fashion. Constructing a private communication network is not an adequate solution when facing the new scenario posed by an open energy market where the number of agents is indefinite. This is especially the case of the OASIS function, as provider of widely available information. A solution for the energy market must then follow the security solutions that begin to be standardized in the Internet, for example for electronic commerce.

The basic idea is the building of a dynamic virtual private network on top of the public network. Participants would establish connections through secure protocols, after passing an authentication procedure.

With this type of connection, message contents are encrypted through digital keys. The burden incurred in violating this type of connection is proportional to the number of bits employed to construct the key. Table 1 shows the approximate time needed to break a digital key as a function of its size and available computer hardware [2].

Violating Agent	Equipment Cost	40-bits	56-bits
PC	$ 400	5 hours	38 years
High-performance WS	$10K	12 min	556 days
Mid-range Server	$300K	24 sec	19 days
High-end Server Cluster	$10M	7 sec	13 hours
CIA / other agencies	$300M	.0002 sec	12 sec

Table 1: Keys break effort

For strategic security reasons the US government allows the export of key of up to 40 bits. This is based on a requirement of being able to break any digital communications, in critical situations.

Keys with 40 bit length are largely employed in Secure Sockets Layer (SSL) present in the most popular web-browsers. As in table 1, 40 bit keys do not satisfy security requirements for electronic commerce. Nevertheless, it can be expected that 128 bit kits will be made available shortly, subject to being registered in some form of Registration Office to be defined. This and other alternatives are a hot spot in the Internet discussion forums, mainly those interested in electronic commerce. From this point of view we can see the (monetary) importance of getting a solution in a short time, and for this reason we see extremely good chances of having a solution readily to be applicable to the energy market.

5.5. Graphic Interface Evolution

Control center human-machine interfaces must evolve to cope with overall changes in power system structure. Competition and privatization require that system operation become increasingly profitable. This will naturally lead to reduction of power systems spare capacity and safety margins, meaning that systems will have be operated closer to their limits.

Appropriate system behavior visualization will become a critical issue, and increasing the number of measurements to improve overall observability will be a must. Fine-tuning control requirements will increase substantially operators' responsibilities. They will have to execute increasingly complex tasks requiring technical expertise and experience. Finally, managing a possibly large number of energy trade contracts, not to mention environmental issues, will add new workloads to power system operators.

Obviously, the help provided to operators by special computer applications will become absolutely necessary for utilities to succeed. The current operating model, heavily dependent on operators' expertise, will quickly face extinction.

SAGE already encompasses some advanced applications aimed at helping the operator, including artificial intelligence tools for system restoration [5] and alarm diagnosis [6]. Other applications targeting the new market model are coming soon.

Introducing new powerful applications is not enough, however. It is mandatory to design the man-machine interaction in such a way that operator can use applications efficiently; otherwise, the risk of operational failures caused by human operators errors may become too high. Operators can't waste their (increasingly precious!) time running different applications – often using different power system modeling – and searching for the actually useful pieces of information among massive amounts of data and results, as in the currently used *tool-centered* man-machine interaction paradigm. In the new market context, man-machine interaction has to be shift to the *operator-centered* [7] paradigm: it has to be structured essentially considering the *tasks* operators actually perform, and not around the applications available.

The concept of Intelligent Agents is a promising route to operator-centered interaction, and research is currently being developed to evaluate its use in SAGE. The agents system is divided into Application Agents, responsible for dealing with applications (preparing data, running, and extracting relevant results), and Interface Agents, conceived in accordance with operators tasks and responsible for activating the Application Agents.

Another SAGE interface research subject is the representation of power system behavior. It has been shown [8] that enhanced and non-conventional representations of power system diagrams can substantially improve operator's understanding of system behavior. This increases operator's productivity and reduces the risk of operational errors.

Graphical software is a very dynamic area. If a user interface software is developed with a strong coupling to a specific graphic system, it is very likely that it will become obsolete within a few years. SAGE's user interface relies heavily on Object-Orientation and provides a clear separation between the "stable" and the "volatile" code components, thus allowing for easy graphical software evolution.

Internet is changing the way we work, and this will be reflected on the requirements for the availability of selected pieces of power system information on the Web. The integration of SAGE's user interface to Web browsers or similar solutions is currently under careful evaluation.

6. Conclusion

SAGE's implementations in the electric power sector, new tools developments and the intrinsic flexibility of SAGE heterogeneous architecture were presented in this paper.

These features allow us to foresee a successful application of SAGE to power sector information processing in order to fulfill the requirements of the new wholesale energy market scenario.

8. References

[1] Vieira Filho, X., Gorenstin, B.G., Salgado, E., Pilotto, L.A.S., "The Technical Challenges of a Modern Control Center in a New Power Sector Structure", to be presented at Cigré - International Conference on Large High Voltage Electric Systems, Paris, France, September 1998.

[2] Lenstra, A. K., Manasse, M. S., "Factoring with two large primes", *Advances in Cryptology--Eurocrypt '90*, PPMPQS factoring method, 72-82, Springer-Verlag, Berlin, 1991.

[3] Lima, L.C., Machado, P.A., Oliveira Filho, A.L., Pereira, L.A.C., Azevedo, G.P., "Design and Development of an Open EMS", Athen's Power Tech., September 1993, Atenas, Grécia.

[4] Machado, P.A., Lima, L.C., Pereira, L.A.C., Azevedo, G.P., Oliveira Filho, A.L., Silva, A.J.S.R., Amorim, M.F.P., Roméro, S.P., "Desenvolvimento de uma Nova Geração de Centros de Controle", *XII SNPTEE*, Outubro 1993, Recife, Brasil.

[5] Martino, M.B.M., Silva, M.B., Macêdo, J.D., Pitta, R.L.A., Figueiredo, M.V.F., "Expert Systems for Power System Restoration", to be presented at VI SEPOPE - Symposium of Specialists in Electric Operational and Expansion Planning, May 1998, Salvador , Brazil.

[6] Silva, V.N.A.L., Ribeiro, G.F., Lourenço, C.R.S.H. "Application of Artificial Intelligence in Electric Power Systems Diagnosis", to be presented at VI SEPOPE - Symposium of Specialists in Electric Operational and Expansion Planning, May 1998, Salvador , Brazil.

[7] Khare, R., Christie , R., "Towards an Ideal Operator Assistant: Development of a Framework", *1995 IEEE International Conference on Systems, Man and Cybernetics,* October 1995, Vancouver.

[8] Azevedo, G.P., Souza, C.S., Feijó, B., "Enhancing the Human-Computer Interface of Power System Applications", *IEEE Transactions on Power Systems*, Vol. 11, No. 2, May 1996.

[9] Clayton, R.E., Mukerji, R., "System Planning Tools for the Competitive Market", *IEEE Computer Applications in Power*, Vol. 9, No.3, pp.50-55, July, 1996.

[10] Cauley, G., Hirsch, P., Vojdani, A., Saxton, T., Cleveland, F., "Information Network Supports Open Access", *IEEE Computer Applications in Power,* Vol. 9, No.3, pp.12-19, July, 1996.