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A Multi-Agent Design and Implementation of An Internet Based Platform for the Remote Monitoring and Control of the Cameroon Power Network

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***Abstract*— This article presents a Multi-Agent model for the real-time monitoring and control of distributed systems incorporating remotely located subsystems. Each agent is designed to perform one of three generic functions – monitoring, control or remote communication. The agents interact and share information via the Internet, using the TCP/IP suite of protocols. The application of the model to the Cameroon power system is presented, to illustrate the advantages of the approach over conventional modeling strategies.**

The proposed distributed control system incorporates control stations, located in distant geographical locations. Two of the control stations are located at the hydro-electric stations, while a third station is located at the distribution center. The stations inter-change information through the Internet while the security aspects are enhanced by virtual-private-network technology.

***Index Terms*— Monitoring, Remote Control, Power System, Distributed System, Multi-Agent System, Internet**

I. INTRODUCTION

Real-time Control Systems are widely used in many industries. Such systems vary from small-scale process plants, confined to a single geographical location, to large-scale distributed systems, covering a wide geographical area.

The Cameroon power system (Fig. 1) consists of two separate networks – the northern and southern grids. The northern grid is supplied by one hydro-electric generating station (Lagdo) and a thermal plant. The southern grid is supplied by two hydro-electric generating stations and four thermal plants. Hydro-electric power accounts for 77% of the total output of 1028MVA.

The southern grid incorporates two remotely located hydro-electric generating stations, a power distribution center, several thermal plants and hundreds of kilometers of transmission lines. That grid, which produces and distributes over 91% of the total energy, is considerably more extensive than the northern grid. Its main components include:

- 225 KV and 90 KV transmission lines, covering a distance of 484 Km. The 225 KV line transports energy from the Songloulou hydro-electric station to a distribution station located at Mangombé. The 90 KV line transports energy from the Edea hydro-electric station to a second distribution station located at Logbaba.
- A high-voltage transmission network, covering a distance of 657 Km.
- A 15 KV medium-voltage transmission network.

A low-voltage transmission network with 220V single-phase and 380 three-phase lines.

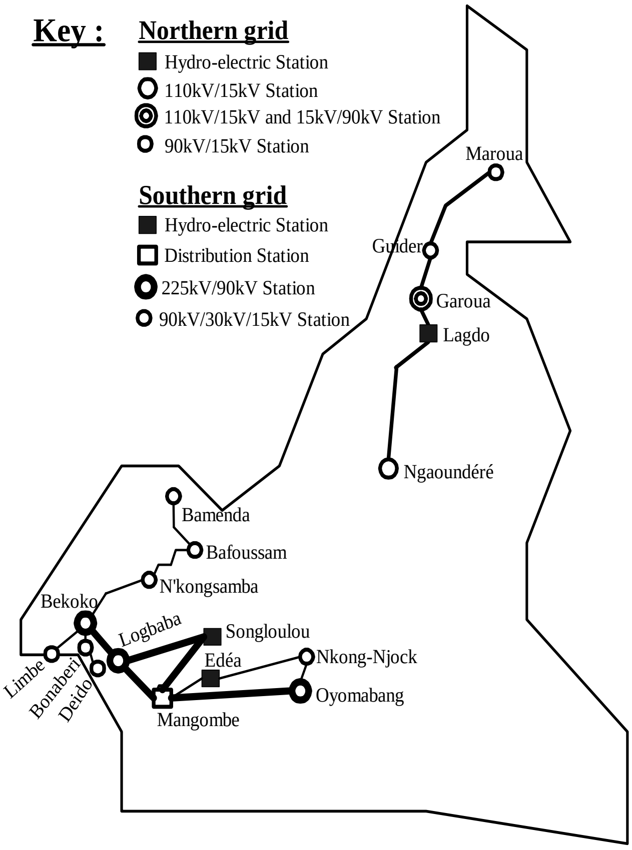


Fig. 1. The Cameroon Power System

The transmission lines in both networks are aerial, which makes them vulnerable to perturbations. Furthermore, the topology of both the medium and low-voltage networks partly accounts for the inefficiency in power transmission.

For over four decades, the southern grid has functioned without major problems, but in recent years Cameroon is facing an unprecedented energy crisis characterized by frequent load-shedding – a phenomenon which undermines the economic and technological development of the country.

Several factors contribute to the energy crisis. Some of the major ones include obsolescence of equipment, a rapidly increasing population and inefficient automatic control systems.

The control strategy applied to the hydro-electric stations has two main weaknesses. First, the set points of the control loops are primed manually based on statistical estimates of power consumption. Also, the volume of water driving the turbines is estimated based on statistical data on seasonal variations. Considering the long distances between the dams and the turbines and the environmental changes which cause major fluctuations in water level, this approach is no longer appropriate. This problem has been addressed by Kenfack [1]. The more general problem of optimizing the scheduling of large scale hydro-thermal power systems has also been addressed by Ngundam, Kenfack and Tatietse [2].

These problems are the main motivation for the development of a Distributed Real-time Control System to replace the outdated semi-automatic controls which are currently used. The design of real-time control systems for power networks has been explored by various researchers [3] [4]. Kenneth & Al [5] have proposed the use of a real-time system for monitoring the power network in the state of New York, based on Internet communication protocols. This evolution in technology has several implications for the Data Communication Systems which implement the real-time algorithms. This problem has been highlighted by several researchers [6] [7] [8] [9]. Specific design considerations are required for Local Area Networks and Wide Area Networks. Other considerations depend on whether the computer network is required to function as an Intranet or to have full Internet functionality. The details of the network configuration must be stored in a client-server data base which provides information on the state of the system [8] [10].

Many researchers have proposed the use of TCP/IP networks for real-time applications. However, such an approach may pose some practical problems when the real-time system is designed to monitor a power network [5].

Most of the references included in this paper address the problem of real-time monitoring [11] [12] [13]. Our article places emphasis on the real-time control strategy. TCP/IP protocols are appropriate for such applications. For one thing, the speed of operation of TCP/IP networks is quite considerable. But the specificity of the proposed system is its distributed nature (remotely located control stations).

The proposed control system consists of three remotely located computer-controlled stations which exchange information through the Internet. In recent years, there has been widespread interest in the use of the Internet for control and monitoring of power distribution networks [14]. Some researchers have also considered strategies for fault detection [15].

In view of the distributed nature of the system and the reactive and cooperative nature of the constituent subsystems, the technology of Multi-Agents is more appropriate for its implementation.

The paper is structured in eight parts. This introduction (part 1) is followed by a description of the Distributed Real-time Control System, in part 2. The Internet-based communication aspects are presented in part 3. The presentation of the advantages of the Multi-Agent approach and the various Agents of distributed real-time control system are then presented, in part 4, followed by the architecture of the system, in parts 5 & 6. The simulation of the system is described in part 7 while part 8 presents the main conclusions and perspectives for further work.

II. THE DISTRIBUTED REAL-TIME CONTROL SYSTEM

In view of the extensive geographical distribution of electric power systems, it would be prohibitively expensive to design correspondingly extensive computer networks for the control of such systems. The Internet provides a way round this difficulty. In this article, we propose a mixed architecture which strikes a compromise between centralized and distributed control.

Each node of the system is a centralized controller for the power system equipment directly connected to it, but the node can also transmit information to remotely located parts of the network. The configuration of the Distributed Real-time Control System is shown in figure 2. The system consists of three computer-based control stations which are inter-connected via the Internet. Two of the control stations are located at the hydro-electric generating stations, in Edea and Songloulou, while the third station is located at the power distribution center, in Mangombé.

A. The Hydro-electric Control Stations

The hydro-electric control stations have the same configuration, the only difference being that the Songloulou power plant has a much higher power output than the Edea plant.

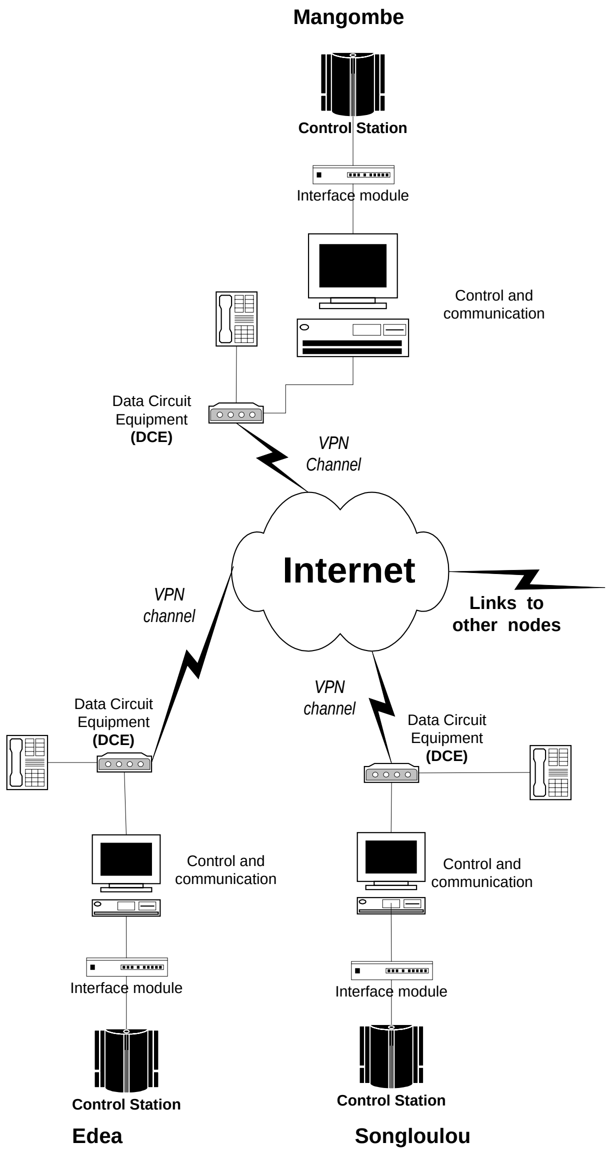


Fig. 2. Configuration of the Distributed Real-time Control System [16]

The schematic diagram of figure 3 shows the configuration of the control stations.

The generating plant consists of an alternator which is driven by a turbine and a dynamo. The turbine is driven by a large volume of water which falls from a considerable height. As the water impacts on the turbine blades, its potential energy is converted into kinetic energy. The ratio of energy converted depends on the angle of the polar wheel in the turbine. By manipulating this angle, the speed of the turbine can be controlled. The turbine drives a rotor which interacts with the magnetic field inside the alternator to generate electric power, which is represented by the voltage and current at the output of the alternator. The hydro-electric plant is, thus, a multivariate control system with two inputs and two outputs. The strength of the magnetic field inside the alternator is a function of the field voltage supplied by the dynamo. The field voltage depends on the excitation voltage applied at the input of the dynamo. As the high-speed rotor cuts through the flux of the magnetic field, it generates an electric field inside the alternator. It is this field which is responsible for the electric power produced by the alternator.

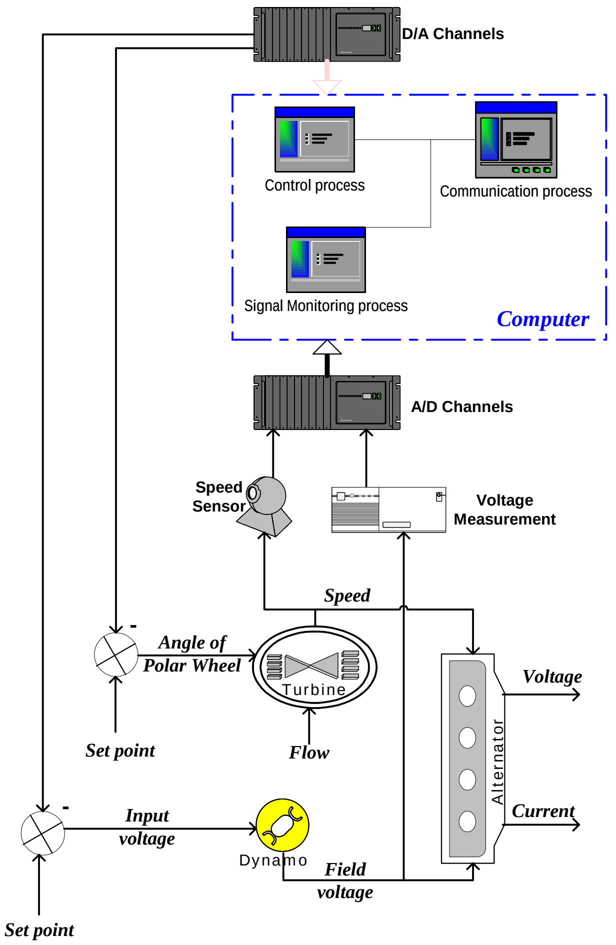


Fig. 3. Schematic Diagram Showing the Configuration of the Hydro-electric Control Stations [17]

The mother-board of the computer is fitted with a data-acquisition card which is a multi-channel zero-order-hold with multiple Anologue-to-Digital (A/D) and Digital-to-Analogue (D/A) conversion channels. The turbine speed and alternator field voltage are measured by sensors and the signals are processed by electronic interface circuitry before being applied to the A/D channels of the zero-order-hold. The control algorithm, programmed in the computer, calculates the values of the control signals to be applied to the turbine and dynamo inputs. These signals close the control loops.

The control software is designed as concurrent Processes which implement the Foreground and Background tasks to be performed by the real-time control station. The foreground task implements the discrete-time control algorithm which is based on sampled data obtained from measurements of turbine speed and field voltage. A sampling frequency of 10 Hertz is used, to ensure adequate stability margins of the two control loops. One of the background tasks interrogates the remote Power Distribution Control Station to obtain data on the power output supplied to the transmission lines. This data is used to prime the set points of the two control loops of the hydro-electric control stations.

B. The Power Distribution Control Station

The Power Distribution Control Station has two functions:

- It switches power to the high-voltage transmission lines, ensuring that the power transmitted at any one time does not exceed the power output from the generating stations

- It keeps a record of estimated hourly power consumption figures. This data is communicated to the hydro-electric control stations, to prime the setpoints.

III. INTERNET-BASED DATA COMMUNICATIONS SYSTEM

Gupta and Varma [10] have described a distributed data base which provides real-time information on the state of the Indian power network. While such a data base has the utility of providing a variety of information to various researchers, it is based on a Client-Server architecture. This makes it widely accessible to many users. In this project, we propose a multi-level architecture in which control information can be directly used by the system. Each computer can play the role of a client or a server. Figure 2 shows how the remotely located control stations are networked into a single system. The Internet serves as the backbone of the network. The design of the network is based on a client-server architecture which facilitates the interchange of information between the control stations. Apart from the usual network design considerations such as choice of hardware, interconnection of the hardware for optimum speed, choice of communication protocols and configuration of the servers, particular attention has been given to security since the system must function as a private network.

A. Networking Techniques and Protocols

Each of the control stations constitutes a node of the network. Each node is designed to perform three functions – control, monitoring and communication with other control stations. The computer in each node is connected to a DCE (Data Circuit Equipment) which is, in turn, connected to the Internet by a high-speed link.

The transmission of information through the network is based on TCP/IP (Transmission Control Protocol/ Internet Protocol) – a suite of protocols used in the design of most networks. The system is designed as an open-ended TCP/IP network to allow for future expansion through the addition of new control stations.

The existence of a process for real-time control poses additional problems for the communication system. Classical Internet protocols can not guarantee the functionality required by the real-time control process. For this reason, the use of the Real-Time Protocol (RTP) is envisaged [18]. This forms part of the new suite of Internet protocols. The packets transmitted by RTP will carry the instructions for the real-time control of the network. RTP is designed to function in a real-time environment. In addition to network performance requirements, the implementation of the network must make due allowance for security of data. The high-speed links connecting the data switches to the Internet are configured based on Virtual Private Network (VPN) technology to provide private communication channels which are protected from unauthorized users.

The large bandwidth of the system is underutilized at the moment. For this reason, the telephones in the control stations have been connected to the channels of the network to utilize some of the extra capacity.

B. Organization of Software for Real-time Control

The software is designed as a multi-tasking system incorporating Processes which are executed concurrently. The computer in each node executes three processes- one for control, one for signal monitoring and another for communication with the computers in the other nodes. The control process is a fore-ground task while the other two processes are background tasks. The foreground task has a higher priority and is therefore executed with a higher frequency than the background tasks. The distributed real-time control system, thus, incorporates nine software processes, as illustrated in figure 4. The open-ended architecture of the physical network is also reflected in the software. In future, more processes can be added to the system. The principle of three processes per node will always be maintained to ensure compatibility between the new nodes and the existing system.

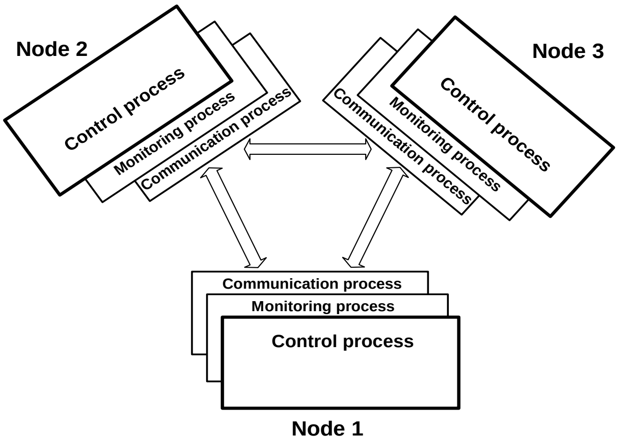


Fig. 4. Real-time Multi-tasking Software

IV. MULTI-AGENT MODELING

A. Advantages of the Multi-Agent Approach

Two main approaches are generally used in modeling physical systems. One approach, based on the interconnection of subsystems, has the disadvantage of not reflecting the distributed, reactive and interactive nature of power systems [19]. The second approach, based on systemic concepts, is more oriented to the representation of the structure of systems. This approach is inappropriate for the description of the dynamics of a system [20] [21]. This deficiency makes the systemic approach inappropriate for power systems.

The multi-agent approach, on the other hand, is centered on the notion of interactions between the constituent elements of a model [22]. A multi-agent system is a collection of processes, which are executed concurrently, share common resources and communicate with each other [23]. The functionality of each agent is governed by the set of rules assigned it. An agent can, thus, be designed to perform the function of monitoring or control depending on the rules assigned to it.

In [11], John M. Hawkins proposes a control model incorporating an agent whose role is to facilitate transactions between production and distribution stations. It is just like a distant communication agent in our system. We will present in the following paragraph the tasks expected from our agents.

B. Multi-Agent Modeling of the Cameroon Power System.

The system is modeled as a collection of Agents which collaborate to effectuate decentralized control and monitoring of the power networks. The Agents are classified according to the functions they perform. There are three generic functions – monitoring, control and communication.

– Monitoring Agents: The monitoring Agents collect and filter information on the state of the power networks. They must periodically interrogate the power networks to obtain updated information about their state. Consequently, the computers, which implement these Agents, must have local memories for the storage of the frequently changing data. The Monitoring Agents scan the sensors to check if the data they contain is different from previously stored values. When this is the case, the local memory is updated and the updated parameters are sent to the Control Agents by the Remote Communication Agents. The Control Agents also generate log files, which can be consulted by the Control Agents before certain decisions are taken. The log files can also be consulted by the network operators.

– Control Agents : The control agents calculate the values of the control signals to be applied to the control stations. These calculations are based on the set points of the various control loops and the measurements obtained from the various sensors. The parameters received from the Communication Agents enable the control Agents to compute the control signals to be applied to the control loops.

– Remote Communication Agents : The Remote Communication Agents handle the exchange of information between remotely located control. They convert information into packets before transmitting it to the remote machines.

The data shared by the various agents is transmitted via the Internet using the TCP/IP suite of protocols.

V. ARCHITECTURE OF THE MULTI-AGENT SYSTEM

Figure 5 shows the interactions between the various agents. The arrows at the end of the links indicate the directions of information flow.

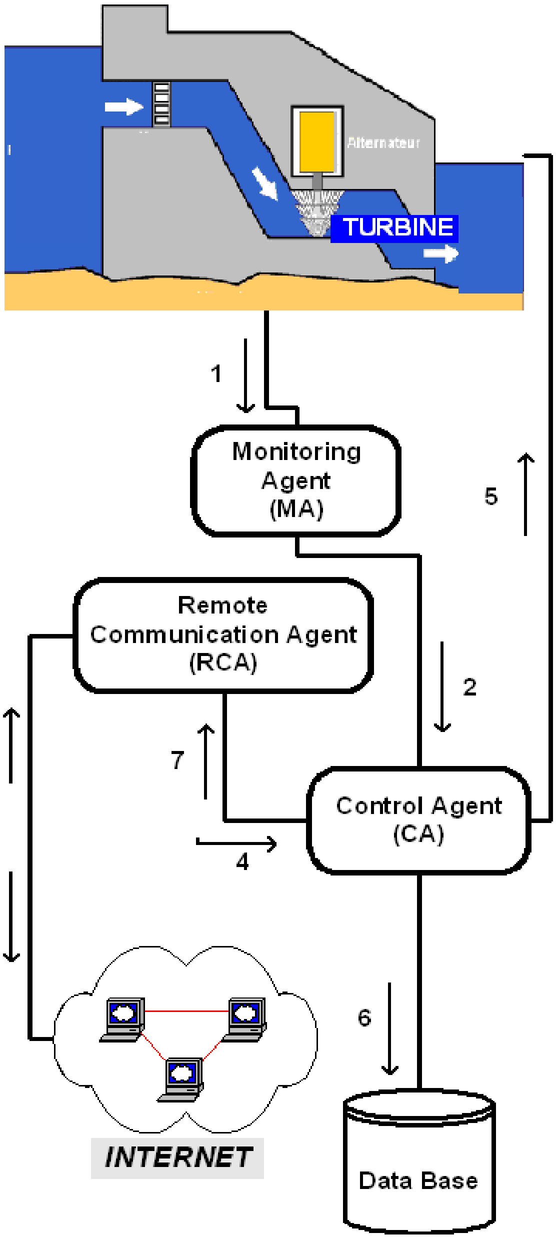


Fig. 5. Multi-Agent System Architecture

The system architecture, in fig.5, shows how the various sub-systems interact to produce the overall system functionality. There are two different system configurations, corresponding to the:

-Control of the Generating stations

- Control of the Distribution Stations

The system architecture in fig 5 corresponds to the control of the generating stations. The arrows indicate the directions of information flow between the sub-systems.

The Interactions numbered from 1 to 8 are described as follows:

1:Transmission of information from the sensors, implanted in the physical system, to the Monitoring Agent.

2: Transmission of parameters to the Control Agent.

3: Reception (via the Internet) of active and reactive power parameters, transmitted from the Remote Communication Agent of the distant node to the Remote Communication Agent of the local node.

4: Transmission of the Parameters, mentioned in step 3 above, to the Control Agent.

5: Computation of the current values of turbine speed and excitation current, by the Control Agent, and their application on the physical system

6: Storage of information, on the state of the physical system, by the Control Agent.

7&8: Specification of active and reactive power or other information required by a remote generating station. These interactions (7 and 8) originate from a distribution node. They contain the real-time information used in priming the set points of the controllers.

A useful feature of the system is the logging of data about the system operation. Such data constitutes an important diagnostic tool. The stored data is modeled as a relational database. An excerpt of the database structure is shown in fig. 6.

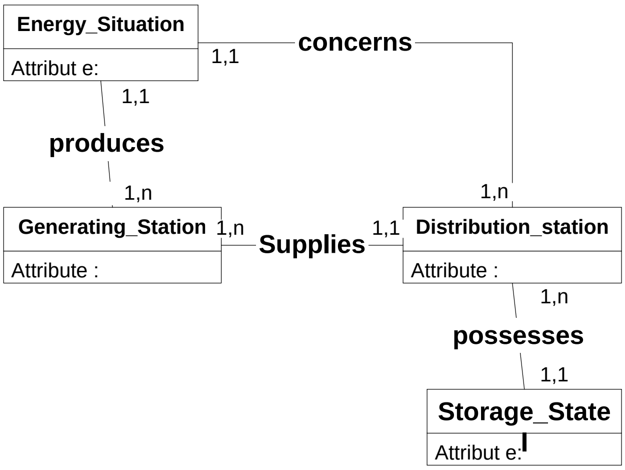


Fig. 6. Extract of the Database Model

VI. CLIENT-SERVER INTERNET BASED ARCHITECTURE OF THE DISTRIBUTED SYSTEM

A Client-Server Internet based system has been designed for the remote monitoring of the electrical power network. A multi-level, multi-tier Client-Server architecture is used, as recommended in [10]. The architecture enables the distribution network to be managed from a computer connected to the Internet/Intranet.

The application software, running in each node of the network (Server), functions in harmony with the control software. The application software is based on the following systems:

- Web Server (Apache) and Script Generator (PHP)
- DBMS (MySQL)

Each of the Servers also functions as a Client for other stations. All that is required to access the platform is a web navigator and appropriate plug-in devices. This can be done either locally or remotely, via the Internet.

Fig. 7 shows the various layers of the application software and the Interactions between them. It should be noted that control applications are not indicated on this diagram.

A brief description of the various layers now follows.

- Presentation Layer

This tier enables the user to interact with the database, through the Web Browser. The interaction, which can be from a remote location, is user-friendly. The Layer is also called User Services Layer since it gives the user access to information. The Layer can also be used to increment and manipulate the database.

- Application layer

The Application tier consists of a Web Server and the Application Logic for data monitoring. This tier is also called the Application Service Layer. The Logic and Rules are stored in separate files using Web Scripts. These files are fully integrated with the main web server. The development of the monitoring system uses APACHE as a web server. This enables in-built services to be shared by several applications. The Application layer is implemented in the PHP language.

Most of the programs which have been developed concern the control and simulation of the physical system. These programs are implemented in JAVA. The functionality of the various Processes was tested by simulating some aspects of the functionality of the physical system.

- Data layer

This tier is also called the Data Service Layer. It manages the data stored in the database or on a storage device. It is from this layer that the relational database is managed. It can be accessed either from the Application Layer or the User Services Layer. The Database in each node is implemented as a MySQL-Server.

The Process, RCA, is a Communication Agent which serves as a gateway between the other Agents associated with the node.

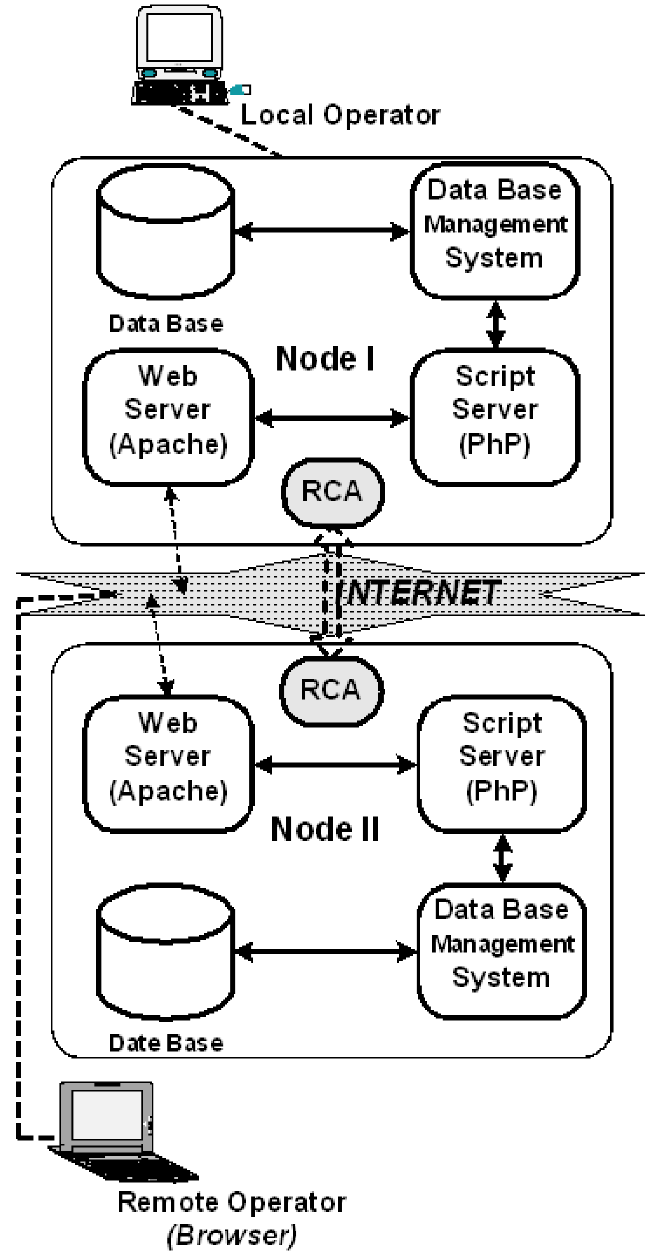


Fig. 7. Multi-tiers client-server architecture

The major benefits of the multi-tier architecture are re-usability, flexibility, manageability, maintainability and scalability.

VII. SIMULATION OF THE SYSTEM

In order to validate the control system, it was necessary to simulate the behavior of the model. The generating and distributing stations were simulated as Java processes which communicate and share information with our system through files, representing the sensors and actuators.

Some of the parameters used in initialising a control station are indicated in fig. 8. They include:

- The maximum speed of the turbine
- The Minimum speed of the turbine
- Maximum and Minimum Excitation Currents

A separate screen is used to enter the parameters of a distribution station.

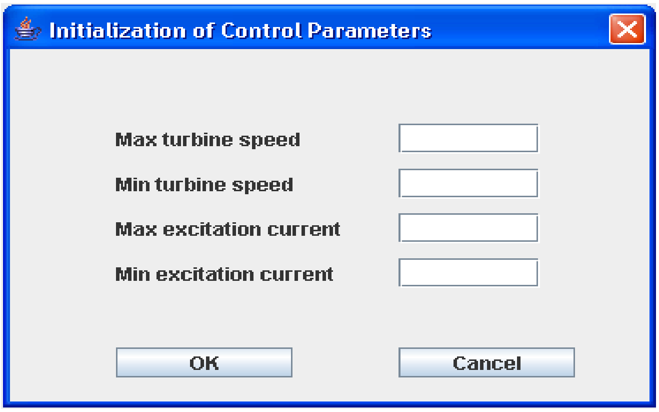
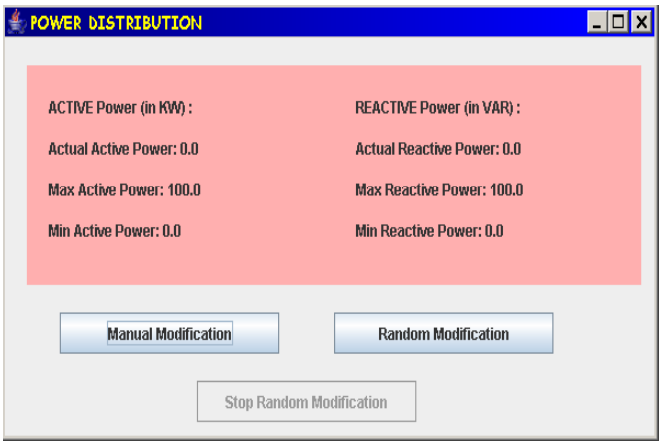


Fig. 8. Initialization of control parameters

The screen in figure 9 allows simulation parameters to be modified either manually or randomly.



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ACTIVE Power (in KW) :                REACTIVE Power (in VAR) :

Actual Active Power: 0.0              Actual Reactive Power: 0.0

Max Active Power: 100.0               Max Reactive Power: 100.0

Min Active Power: 0.0                 Min Reactive Power: 0.0
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Fig. 9. Screen for the modification of simulation parameters

The screen in figure 10 presents the state of a distribution station at an instant in which the Active Power is 50,99 KW and the Reactive Power is 71,29 VAR.

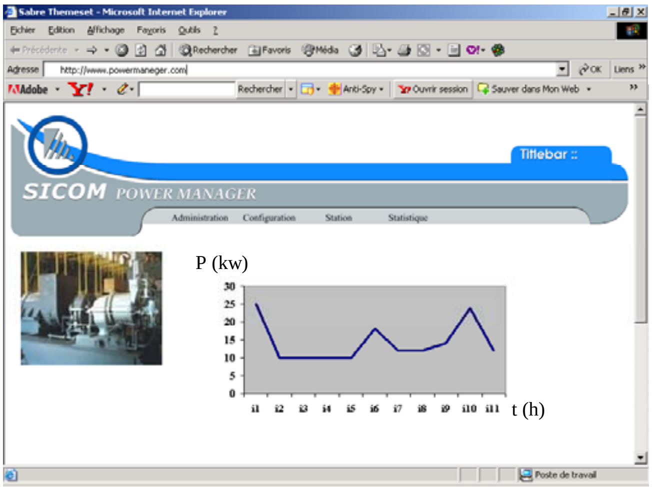

Fig. 10. Variation in Active Power Over a Given Period

When such information is transmitted to a generating station, it is used to calculate the speed of the turbine.

The curve in figure 10 represents variations in Active Power over a given period.

VIII. CONCLUSION

A distributed real-time control system has been presented. The application of the model to the Cameroon Power System has also been described. Internet technology has been used to interconnect remotely located control stations into a single integrated network for data communications and control.

The system is modeled as a collection of Agents which collaborate to effectuate decentralized control and monitoring of the power networks. The Agents in the model interact and share information via the Internet using the TCP/IP protocols. This facilitates the remote monitoring and control of distributed systems.

Each of the control stations in the power system constitutes a node of the network and each node performs three functions – control, signal monitoring and communication with other control stations.

The model has been tested using virtual stations implemented in Java. The virtual stations share data from files which represent the sensors and actuators of a system.

The channels which link the control stations to the Internet are designed based on Virtual Private Network (VPN) technology to protect the system from unauthorized users.

The system is the result of on-going research which was specifically commissioned to design and implement a modern computer-based control strategy for the Cameroon power network.

Future work will focus on three aspects: a detailed analysis of the TCP/IP protocols in order to enhance real-time functionality, an extension of the Multi-Agent model to include a wider set of power system parameters and the implementation of the model on the Cameroon Power System.

IX. ACKNOWLEDGEMENT AND PARTNERS

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