An Internet-based Distributed Real-time Control System for the Cameroon Power Network

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Abstract

This article presents a distributed real-time control system for the southern grid of the Cameroon power system.

The southern grid, which supplies over 90 % of the power output in Cameroon, incorporates two remotely located hydro-electric generating stations, a power distribution center, several thermal plants and hundreds of kilometers of transmission lines.

The proposed distributed control system incorporates three computer 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 three stations inter-change information through the Internet while the security aspects are enhanced by virtual-private-network technology.

1. Introduction

The Cameroon power system 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, 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.

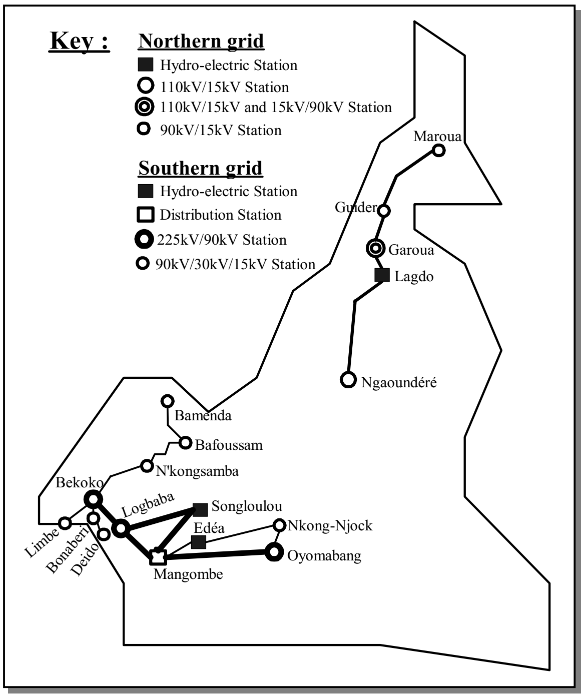

Figure 1. The Cameroon electric power system

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 systems has been explored by various researchers [3] [4]. Some of the systems are very large-scale power systems. For instance, 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 innovation 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 [10]. Some researchers have also considered strategies for fault detection [14].

The article is structured in five parts. This introduction (section 1) is followed by a description of the Distributed Real-time Control System, in section 2. The Internet-based communication aspects are presented in section 3. The main conclusions from the research are presented in section 4. Section 5 presents the perspectives for further work.

2. The Distributed Real-Time Control System

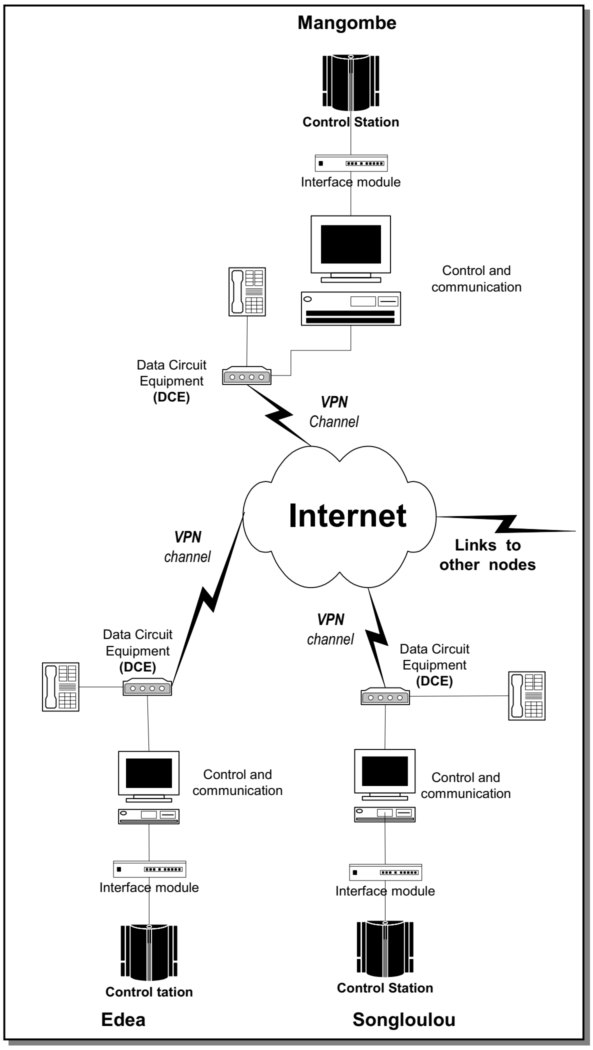

Figure 2. Configuration of the Distributed Real-time Control System

Most power systems are very extensive and are distributed over a wide area. It is prohibitively expensive to design computer networks on the same physical scale as the power 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 centre, in Mangombé.

2.1. 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. 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.

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.

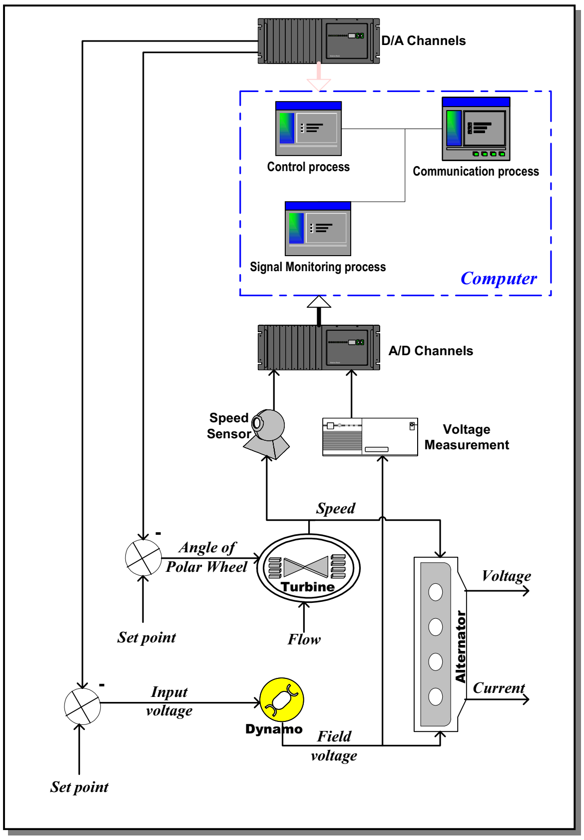

Figure 3. Schematic Diagram Showing the Configuration of the Hydro-electric Control Stations

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.

2.2. 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.

3. 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 three-tier 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.

3.1. 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 real-time control process 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 [15]. 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.

3.2. Design 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.

- The control process calculates the values of the control signals to be applied to the control stations. These calculations are based on the setpoints of the various control loops and the measurements obtained from the various sensors. The parameters received from the monitoring process enable the control process to compute the control signals to be applied to the control loops and to transmit information to the communication process about the state of the local system.

- The monitoring process collects and filters information on the state of the power network. It must periodically interrogate the power network to obtain updated information about its state. Consequently, the computer which implements the process must have a local memory for the storage of the frequently changing data. The monitoring process scans 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 parameters of the control process are modified. The control process also generates a log file, which can be consulted by the control process before certain decisions are taken. The log file can also be consulted by the network operator.

- The communication process handles the exchange of information with the other control stations. It converts information into packets before transmitting it to a remote machine, through the VPN channel. It receives data representing the state of a local control station and transmits it to a remote control station via the Internet.

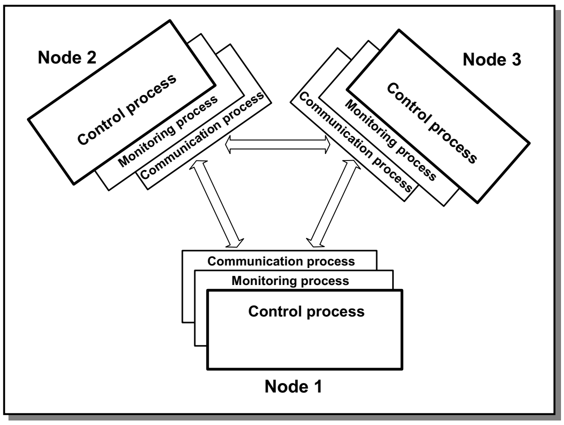

Figure 4. Real-time Multi-tasking Software

4. Conclusions

A distributed real-time control system has been presented. The system uses Internet technology to interconnect remotely located control stations into a single integrated network for data communications and control.

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 networking of the control stations is based on TCP/IP technology and is designed to provide an open-ended architecture to allow for future expansion of the network.

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.

5. Further Work

Future research on the project will focus on three main aspects :

- Extension of the Computer Network. More nodes will be added to the network to monitor and control other parts of the southern grid.
- RTP (Real-time Protocol) Functionality. The real-time control algorithm will be modified to take full advantage of the functionality of RTP.
- Optimal Control. An optimal control strategy will be explored and the results compared with those obtained from the current system.

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