

COMPUTATIONAL SYSTEM FOR THE REMOTE OPERATION OF A PROTOTYPE HYDROELECTRIC PLANT THROUGH THE WEB

SISTEMA INFORMÁTICO PARA LA OPERACIÓN VÍA WEB DE UNA PLANTA PROTOTIPO DE GENERACIÓN HIDROELÉCTRICA

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ABSTRACT: This article describes the development of a software system oriented to operate a prototype hydroelectric power generation system (SGEH) via the Web. The SGEH located at the Universidad del Valle campus emulates hydraulic power based on the IEEE 1010-2006 standard. This system includes remote operation capacities and user management protocols. JavaScript, AJAX, and Java Servlets applications were used. Three different types of users with complete or restricted privileges were considered: the administrator, the operator, and monitor users. The software system restricts simultaneous access to only one administrator, one operator, and up to 23 users on a local area network, which facilitates teaching and research activities in hydroelectric power generation systems.

KEYWORDS: remote operation, hydroelectric center emulation, user management, power generation, operation and monitoring via Internet, Web interface

RESUMEN: El artículo describe la implementación de un sistema informático para la operación vía Web de una planta prototipo de generación de energía hidroeléctrica. La planta SGHE localizada en la E.I.E.E de la Universidad del Valle emula una planta hidráulica basada en el estándar IEEE 1010-2006. El sistema incluye capacidades remotas y protocolos de gerenciamiento de usuario. Se usaron las herramientas JavaScript, AJAX y Java Servlets. Fueron considerados tres diferentes tipos de usuario con privilegios propios. El sistema restringe el acceso a 23 usuarios y un solo administrador en una red de área local facilitando las actividades de docencia e investigación.

PALABRAS CLAVE: operación remota, emulación de planta hidroeléctrica, generación de energía, control remoto vía Web

1. INTRODUCTION

The development of energy in a country is bound to the advancement of the strategic areas related to the resources that it possesses. The development surrounding Colombia's hydraulic resources is historically recognized. Research to achieve advances in the field of hydroelectric generation is needed, as well as access to laboratories in which procedures and processes that update and optimize power conversion and at the same time allow for the formation of professionals according to the new power needs. These spaces are usually found in research laboratories, some of which are specialized in one area of knowledge

or others which investigate the generality of the process. In Colombia, the majority of electric power is generated by hydroelectric centers (64%), followed by thermoelectric centers with 33% [1]. An increase in the percentage of hydro-generation is visualized for between 2008 and 2018, which will increase the country's generation capacity to 2991 MW [2]. In view of the necessity of generating hydroelectric power and considering that Colombia is a country very rich in hydraulic resources [3], trained personnel in the operation of SGEH is needed; this is why it is necessary to implement training, research, and teaching laboratories related to power generation systems. Such laboratories together with information systems allow

one to diffuse and share knowledge and tools which in some places are of difficult acquisition [4]. Among such technologies we find GSM, PSTN, and the Internet, among others [5]. One of the software developments is remote laboratories which allow the use of a real system for the controlled experimentation, but from a place external to the location of the system [6].

To this effect, the design and implementation of an interface web for remote operation through Internet of a modular hydroelectric power generation system was carried out. That implementation allows for us to study the dynamic of its variables emulating the operation of a hydroelectric central (CHE) in such a way that would strengthen the teaching of hydroelectric generation systems (SGEH) whether local and/or remote.

2. HYDROELECTRIC POWER GENERATION SYSTEM (SGEH).

The power generation system located in the Electrical and Electronic Engineering School (EIEE) of the *Universidad del Valle* can be subdivided into three parts: the plant with its mechanical and hydraulic components, the sensory system of variables which allows the control of the system to be carried out based on the controller of the programmable automation SNAP PAC R1 of OPTO 22, and the interface which allows the monitoring and remote operation (Fig. 1).



Figure 1. Power generation system

The SGEH has an operation sequence that includes a process of a starter, synchronization, connection, operation in potency, and disconnection [7].

3. SOFTWARE SYSTEM FOR REMOTE OPERATION

In order to carry out the implementation of the software system for remote access, a desktop HP Pavilion A6620LA was used which fulfills the function of the server equipment and where the Web application was accommodated; an Ethernet/FastEthernet web card was added to the server which achieves the connection with the controller exclusively. For the visual monitoring of the system an IP D-LINK DCS 920 camera is used. Figure 2 shows the general schema of the connection of the physical elements for remote operation.

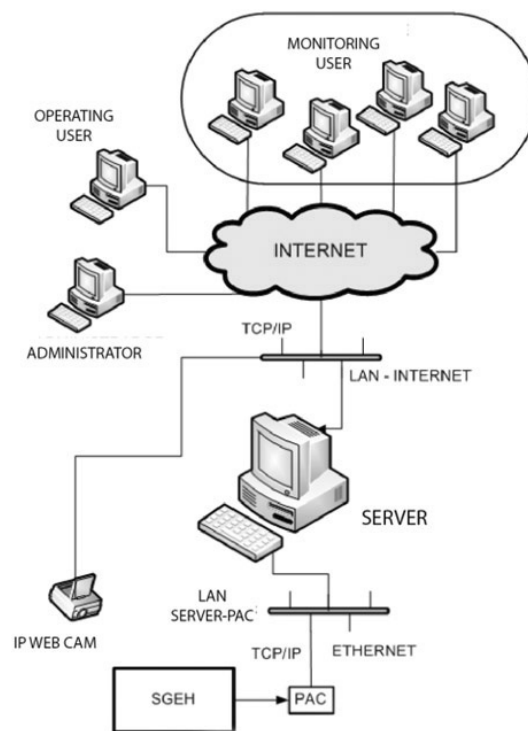


Figure 2. General schema of the physical connection for remote access

The communication interface includes the development and implementation of the database and the graphic user interface (GUI); the OptoDataLink configuration which is a software included in the PAC Project Professional of the OPTO 22 package; the creation of the server application for users' management; creation of the application for the exchange of data among the GUI and the database and the corresponding modification in the control sequence in order to emulate hydroelectric systems variables that are not present in the SGEH. In addition, ODBC and JDBC were used like standards

regarding the interaction with a database. The video of the IP camera is visualized in the GUI through Applets of Java. The communication interface structure is shown in Fig. 3.

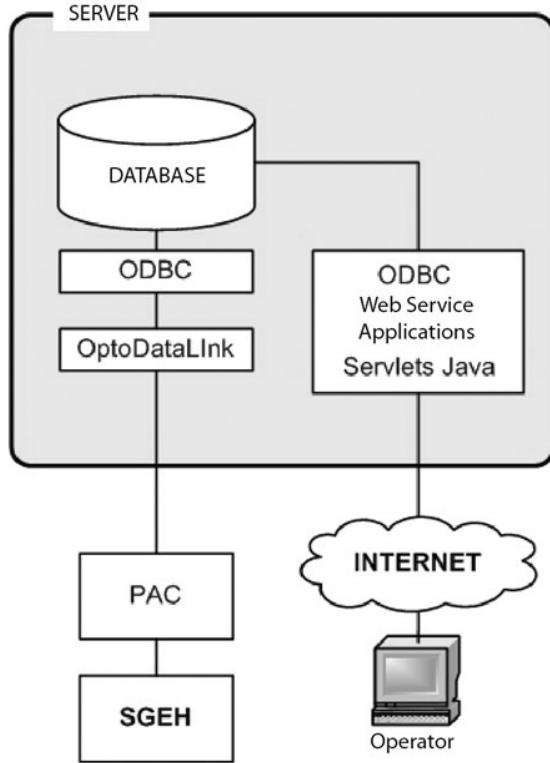


Figure 3. Communication interface schema

3.1. Database

MySQL 5.0 was used for the creation of the database. Administration and maintenance was done using the PhpMyAdmin tool. It was chosen considering that it is free software with the necessary tools for its implementation and easy use.

The database created was denominated “sgeh” in whose structure appear tables called “accesses”, “plantdata”, “events”, “orders”, “systemtrace”, “recordorders, and “users” related by the users_id as shown in Fig. 4.

In the structure, the “orders” table is not related to the others since it is a table of only one record which is overwritten when there is a change in one of its fields and it only stores the last order given to the SGEH; the fields of this table are reinitiated when that order is taken from the database to the PAC.

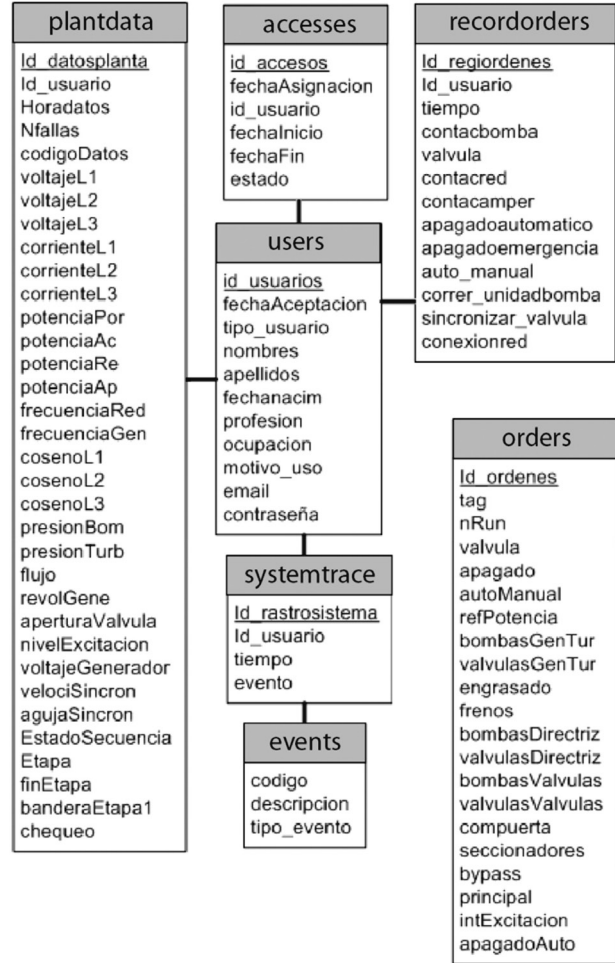


Figure 4. The “sgeh” database structure

3.2 Web server

The Web server implemented was Apache Tomcat 6.0, free software of open source and free distribution which allows for the implementation of JavaServlet technologies [8]. The program application to carry out the transfer of data was done in Java Servlets in the NetBeans development setting.

3.3. Optodatalink Configuration

OptoDataLink allows, in a simple way, the exchange of data between the PAC and multiple destinations as a database or a file of a text. The option of exchange of data between the database and the PAC was configured in this regard. This allowed for the creation of links that function in only one direction, in this case from the DB table to the PAC or from the PAC to another

different table in the DB, but not in both directions in the same link (Fig. 5).

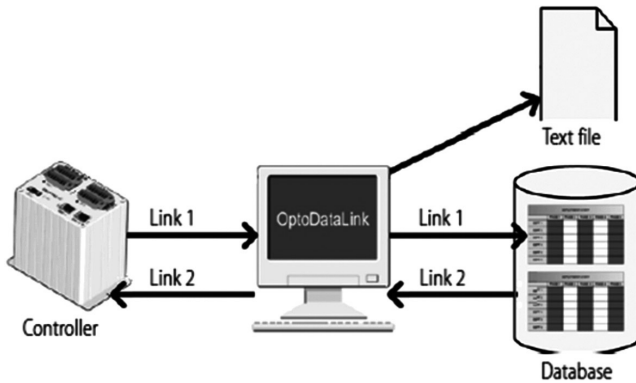


Figure 5. Communication between PAC and database [9]

In the link that was created, the source of the data and their destination was referenced. When the PAC is the data source, numerical variables of the control strategy are related with fields of a table in the database. When the source is the “plantdata” table of the “sgeh” DB, each one of the elements of the table is related uniquely and exclusively with the numerical variables in the PAC strategy [9].

3.4. Application for user management

The application for user management was developed in Java using the NetBeans package. Here, the kinds of users (administrator, operator, and monitor), their privileges, and the actions each one could carry out, were defined.

The administrator user is in charge of managing the users and supervising plant operation. This person can create operator users, can edit, delete, assign, or change their operation date, authorize or disable them for their operation, etc., as well as turn off the plant, or control the valve. The operator user has the privileges of operating the plant, for which he is provided with an interface which simulates the operation of a real hydroelectric; this individual will also be able to bring down behavior records from the plant at the time that he or she operated it. The monitor user is the user with the least privileges in the application. This person can only see the value of the plant variables by remote while it is in operation (Fig. 6).

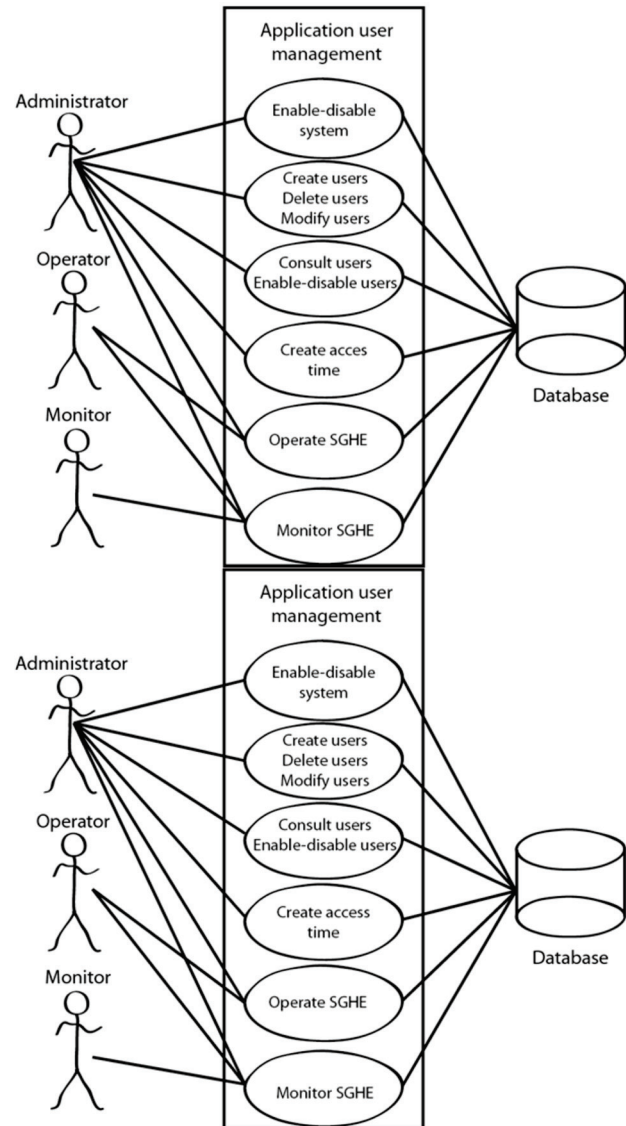


Figure 6. Diagram of cases of use for the user's interface

3.5. Visualization and organization in tabs

The GUIs of each one of the users are Web pages that show the contents according to the tab that the user wants. In this way, if one wants to observe the information of tab 1, then tab 1 should be activated, with which this section of desired information is shown and the rest is hidden (see Fig. 7). The condition mentioned allows all of the information loaded in the Web browser to be maintained, minimizing delays between tab changes.

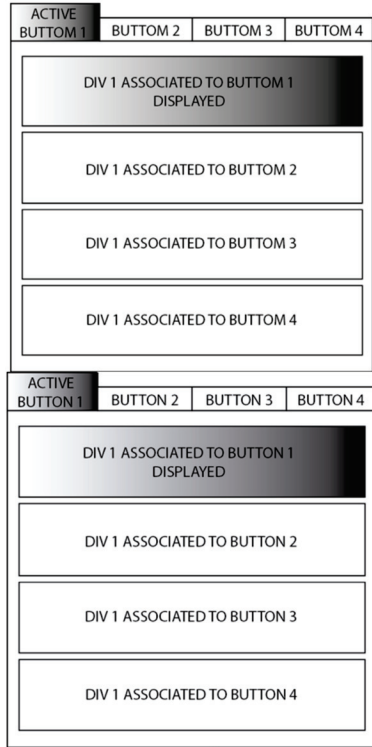


Figure 7. General structure of the GUIs

Moreover, the petition of data to the server is carried out using the AJAX technology whose purpose is to update only the values of the plant variables in the GUI, without updating the complete Web page. From the GUI operator, the SGEH can be operated using the standard IEEE 1010-2006 as a reference that indicates the steps to operate a hydroelectric center. This operation protocol includes the checks before the ignition, the ignition of auxiliary systems, the beginning of the functioning of the generating unit and the connection of the web, and finally, switching off the unit [10].

3.6. Modifications carried out in the control strategy

Although all of the systems that compose a hydroelectric center do not exist in the real SGEH, in the operation GUI elements that are manipulated such as the auxiliary systems, the by-pass valves, the main valve, excitation system, etc. are observed. This was carried out by introducing some variables and blocks in the control strategy that would allow for reflection on the fact that a hydroelectric center was operating without affecting the SGEH control system.

4. RESULTS

4.1. Resulting GUIs

The main page of the administrator user is shown in Fig. 8. From here one enters into the administration GUI and into the users' administration.



Figure 8. Main page of administration

The supervision GUI allows the evolution of the variables as well as the operations determined by the operator. It also allows it to be disabled in the use of the system (see Fig. 9). It unfolds the SGEH video in real time in the same way.

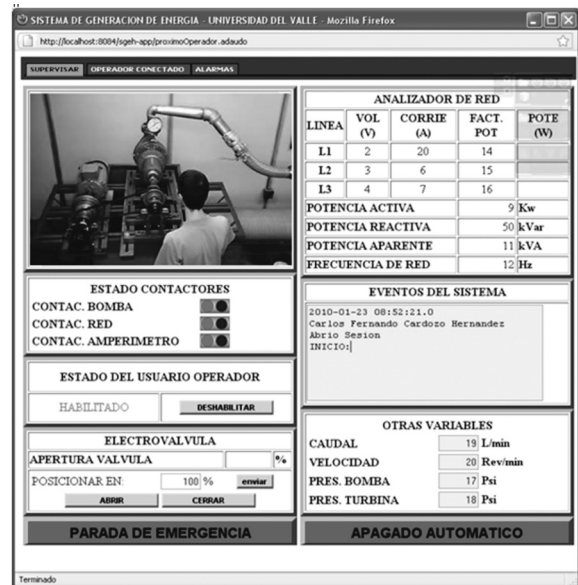


Figure 9. Supervision GUI

The main Web page of the operator user is similar to the one shown in Fig. 8. It is different in that from it one enters into the operation GUI, and records of the functioning of the SGEH can be exported from this page.

The operation GUI is composed of the “center”, “operate”, “synchronize”, “hydraulic”, “mechanic”, “check”, “alarm”, “auxiliary”, and “temporary” tabs. Figure 10 shows the operation GUI with the activated “OPERATE” tab and the SGEH video. For the monitor user, the GUI is visually similar to that of the operator, except that it does not have the operate tab, since these kinds of users are not allowed to see the system video due to limitations in the wide band of the web.

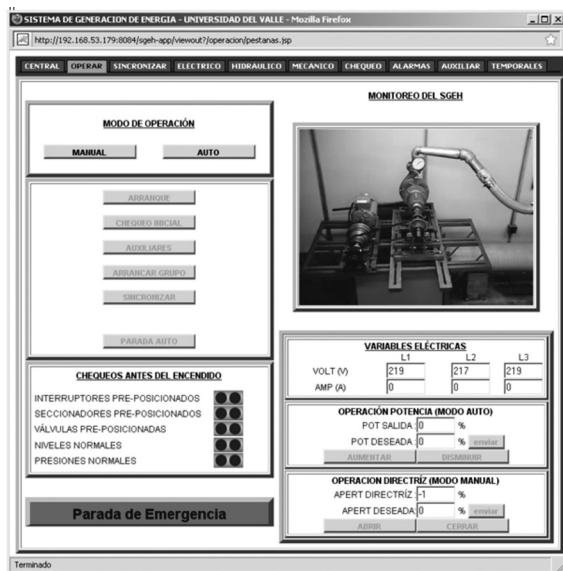


Figure 10. “OPERATE” Tab of the operation GUI

Another of the tabs which make up the GUI is that of alarms, in which the real SGEH alarms are shown, relating them with the alarms of a CHE (see Fig. 11).



Figure 11. “ALARMS” Tab of the operation GUI

The last tab, “TEMPORARIES” shows the evolution of the SGEH variables which allows for their tendencies to be observed (Fig. 12).

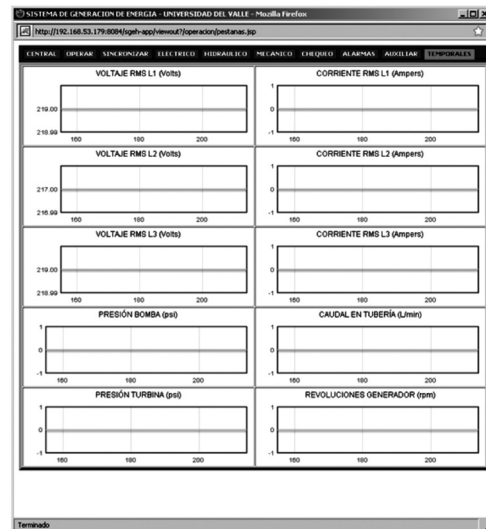


Figure 12. “TEMPORARIES” Tab of the operation GUI

4.2. Load and stress tests on the server

Load and stress tests were carried out on the Web server in order to evaluate the capacity of the response when the most requested service petition was carried out. This refers to the service that the web server renders to the client in a different plant; in this case, this service corresponds to the output data related to the state of the variables of the plant. The SiteBlaster 2.1 of the EXIM corp GNU was used for the development of this test, these tools allow for one to estimate the performance of the server when taking care of the Web services that it offers to the various users who request it.



This service is an HTTP petition which is executed from a remote equipment connected to the same local web of the Web server, at the address: <http://192.168.53.179:8084/sgeh-app/monitorearDatosPlanta.do>, that requests the data stored in the “plantadata” table of the “sgeh” database. With it, the response time of the server rejecting the delays of data transit in the web was evaluated. The data obtained are shown in Table 1.

Table 1. Stress test altering the number of petitions made to the server

TEST NUMBER	TEST CYCLES	YIELD (URLs/s)	RESPONSE TIME (ms)
1	10	91.43	10.94
2	20	85.33	11.72
3	30	96	10.42
4	40	94.81	10.55
5	50	94.12	10.63
6	60	96	10.42
7	70	93.33	10.71
8	80	94.81	10.55
9	90	96	10.42
10	100	96.97	10.31
11	200	99.22	10.08
12	300	98.97	10.1
13	400	98.08	10.2
14	500	117.65	8.5
15	600	104.63	9.56
16	700	97.39	10.27
17	800	97.34	10.27
18	900	96.81	10.33
19	1000	96.97	10.31
20	5000	100.47	9.95
21	10000	98.27	10.18
AVERAGE		97.36	10.31

In Table 1 “(URLs/s) performance” corresponds to the http petitions that the Web server can take care of in 1 second. “Response time (milliseconds)” corresponds to the response time of a petition. “Test cycles” corresponds to the http petitions that were made in each test.

The data in Table 1 shows that 21 tests were carried out beginning with 10 petitions and ending with 10,000. It

can be appreciated that the performance and time values of response are not altered significantly by altering the test cycles. The average value for “performance” of 97.36 URLs/s indicates the maximum number of petitions of the aforementioned service that a server can take care of in 1 second before the applications can carry out the same requests again. The minimum response time on the part of the server (for the *monitorearDatosPlanta.do*) service is given by the average value of “response time” of 10.31 milliseconds

4.3. Measurement of Web traffic for the administration, operation and monitoring GUIs in the client equipment and the server

For the web traffic measurement of the Web application for each one of the users, the Intel(R)VTune(TM) Performance Analysis 9.1 of Intel (Evaluation Version) application was used and was carried out on the local area web of the *Universidad del Valle*, whose available band width is 100 MBPS. The applications that could generate data traffic by Web interface were closed previous to the beginning of the tests.

In Figs. 13 and 14, three peaks located at the same instant of time and with equal amplitude can initially be observed with the difference that on the client side, the peaks correspond to the bytes received, and on the server side they correspond to the bytes sent.

The first peak corresponds to the petition of the validation page; the second, the moment in which the user records satisfactorily; and the third peak is the request for the “supervise” window. One can observe that the “sent bytes” on the server side correspond to the “received bytes” on the side of the remote equipment.

It can also be noticed that 5 seconds after the administrator enters into the “supervise” window there is a high reception of bytes which do not appear in the sent bytes in the server equipment. Those bytes that the remote equipment receives correspond to the transference of the video delivered by the IP camera that transmits the video, and is maintained at approximately 450,000 bytes/s.

This video petition is only carried out while the operator or administrator user has the “supervise” tab active; at the moment that a change of tab occurs, the video

petition ceases until the user again activates it as is observed in Fig. 13.

Similar behavior is observed for the operation Web, and one can only appreciate a high transference of data on the remote equipment side when the “operate” tab is active and a video transmission is carried out. As for the monitor user, the data transference is similar to the display by the administrator user but without the support of the video which is the highest observed in the administrator and operator GUIs.

It was also observed that in the change of tabs, petitions to the server are not made.

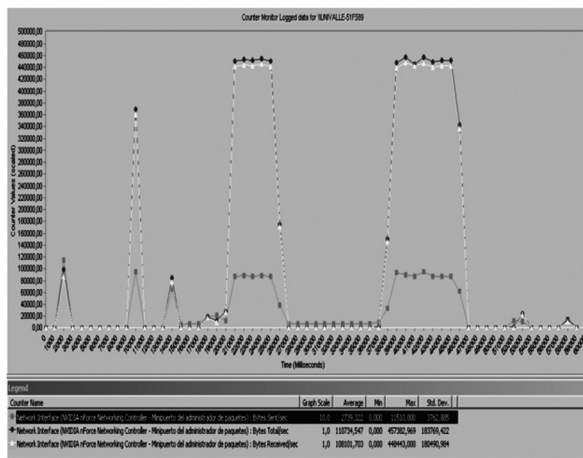


Figure 13. Sent/s bytes, received/s bytes, and total/s bytes in time for the administrator user seen from the remote equipment

In Table 2, the average of sent, received, and total bytes is shown through the web interface in the remote equipment for the administrator user. The average of received bytes is close to 450,000 bytes/s (close to 3 MBPS), the majority provided by the video. For the monitor user, when the transference of the monitoring page has already been carried out, the average is reduced to around 1000 bytes/s.

Table 2. Data obtained for the web traffic seen on the remote equipment

Counter Name	Graph Scale	Ave.	Min.	Max.	Std. Dev.
Bytes sent/s	10	2,739	0	11,510	3,762
Bytes total/s	1	110,734	0	457,782	183,769
Bytes receiv./s	1	108,101	0	448,443	180,490

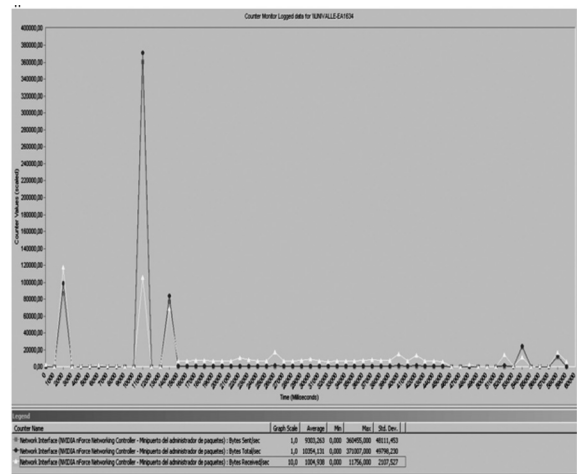


Figure 14. Bytes sent/s, bytes received/s and bytes total/s in the time for the administrator user seen from the server equipment

Table 3 shows the average of transferred bytes in the time of the test’s duration in the server equipment. As for the data traffic in the remote equipment, it can be seen that it is significantly less, since the server equipment only carries out data transference. This is due to the fact that the video is transferred directly from the video server that has the IP camera being used.

Table 3. Data obtained for web traffic seen in the server equipment

Counter Name	Graph Scale	Ave.	Min.	Max.	Std. Dev.
Bytes sent/s	1	9,303	0	360,455	48,111
Bytes total/s	1	10,354	0	371,007	49,798
Bytes receiv./s	10	1,004	0	11,756	2,107

4.4. Test carried out to establish the maximum number of users that a web server can handle

In order to carry out this test, 20 pieces of equipment were used from which the session in the operator mode, then the administrator mode, and subsequently, the monitor sessions were initiated progressively in order to observe the server’s activity as the number of petitions increased. After carrying out a petition for each computer, another browser was used to initiate another session of the monitor user from the same computer until a total of 33 sessions were completed, carrying out petitions of data from the server.

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