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Wireless water resources management for remote installations

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ABSTRACT

Water companies in Greece, and possibly in other countries, are far from the ideal situation, where all their installations are controlled and supervised continuously from a central control room or from any place through internet. The main reasons for that, taking into account the scarcity of the water resources, are the great distances between the water installations and the ground topology which do not allow a low cost conventional infrastructure for the water resources management. In this work a combination of wireless broadband networks, modern systems of signal control and data acquisition, computers/software and telematics have been used to tackle the problem of the water resources management for remote water installations. An integrated system for central control, supervision and real-time water management have been implemented for a water company of the Municipality of Thira in the Greek Island Santorini. The cost of the system is relatively low so that it can be applied even by small size water companies. The application of the proposed integrated wireless system provides the benefits of central, automatic or manual, real time control and early warning for malfunctions without annual fees for networking or any other expenses. On the other hand the system reduces the labour and maintenance cost and improves productivity. The proposed low cost integrated wireless system for the water resources management has also improved the water quality by optimization of the water resources use.

Keywords: Water resources management; Wireless broadband network; SCADA systems; Quality of water

1. Introduction

Supervisory Control and Data Acquisition (SCADA) systems in water resources management usually is applied in parts of installations of water companies, basically in desalination plants or in wastewater treatment plants. Before 1990 the technological means for SCADA systems were poor in features and expensive in cost so that the automatic control and data acquisition systems for water management where narrowed in data loggers and wireless float stops, requiring great human effort. However in the 21st century SCADA systems can be found in almost all the installations where water is treated or distributed. Sewer systems [1–3], waste water plants [4] water distribution systems [5,6] are some of the water installations where SCADA systems are applied.

SCADA systems for large areas to control several installations can be found globally mainly in systems built for river basins and canals after 1990 [7,8]. Rivers, canal and water distribution systems have greater risk of pollution and this produces the need for constant and at almost

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real time monitoring [9,10]. However, SCADA systems for large areas have to overcome communication problems because of the scarcity of the installations. At the same time SCADA system has to combine robustness, security, reliability and finally to be installed at an affordable cost.

In 2001 Syncrony Inc. published a white paper, [11], which describes solutions based in PLC mater terminal unit/remote terminal units communicating each other using wired public transmission media or wireless atmospheric media.

The future trends for water resources management described in 2001 were SCADA systems based on PLCs and the newly introduced intelligent remote terminal units, advanced communication and PC-based software. In 2005 Krenar Komoni from Norwich University [12] tried to classify SCADA systems based on three layers: 1. Communication/networking, 2. Security reliability, 3. Intelligence. Again in 2005 [13] the model was the same but it became clear that communication layer affects security and reliability so that extra intelligence has to be added to overcome problems of communication and to provide robustness. By 2005 [12,13] master–slave topology of the master PLC controlling slave remote terminal units started giving place to pear-to-pear solutions and distributed control systems, because distributed control systems were easy to expand and maintain. Recently most of the SCADA solutions were constructed using any kind of programmable logic controllers and mainly wireless communications [14,15]. Systems upgraded by that time, mainly replaced wired communications to wireless [16].

This work describes how the technological combination of WiFi wireless broadband network, web i/o network logic controller modules and custom SCADA application can be installed and setup after careful planning [15], to successfully create a low cost water management system. The particular SCADA system concerns seven wells, two pumping stations, two reservoirs and one control room. The solution is cost effective, reliable and expandable so it is suitable even for small water companies.

2. Analysis of current situation of water management in Fira Santorini

In the Fira area of the Municipality of Thira (Santorini) in Greece there are 7 remote wells in operation, which provide water in a first reservoir. A pumping station has to elevate the water from the first tank by the help of another booster pump to the main reservoir, which is 200 m higher and 2.5–3 km away than the wells. Before October 2007 some of the wells were connected with wired float stops to the first reservoir and a wireless float stop in the main reservoir was controlling the pumps. Some other wells were controlled by timers set according to previous statistics. Some others were controlled manually. The only data which were kept manually were the total work hours of the pumps and the water chlorine concentration in main reservoir. Water quality was checked monthly in a chemical laboratory.

By September 2006 the plan to install a SCADA system for the water management for the Fira area was started. The most difficult part was to achieve WiFi communication. According the plan two Access points had to be set, one in the water company offices and another in the main reservoir that would be connected together to the pumping station. Then all sites would wirelessly connect in each one of them as it is illustrated in Fig. 1. Radio propagation is not very easy to be predicted in such large areas and so the network did not work exactly as planned. Small modifications and calibrations have provided a very stable and fast network, even in the worst weather conditions. Intelligent web i/o modules were connected to the network and sensors started transporting data around the network. There were difficulties with ground loops in sensor connections which were overcome using isolators or other ways of connecting the sensors.

The construction of hardware and development of software were completed in October 2007 and one month trial period of manual operation accomplished for bug fixes in SCADA and calibrations for sensors. After that period a normal automatic operation started. During normal operation of the system, extreme atmospheric conditions were occurred. One in February 2008 during which extreme cold, thunderstorms, heavy rainfall and wind speed over 11 beauforts had happened and the second during July 2008 where very high temperatures (40°C) took place. The system performed well with minor network delays during these periods, even when power supply failures took place and when larger systems in the area (cellular networks, wastewater treatment plant automation) went out of service because of lightning strikes. Till the end of August 2008 which is nearly one year of operation three damages have happened in sensors. The first two caused due to extreme water pressure and the third because of constant power supply failures. Damage occurred as well in the power supply of a WiFi transceiver during the power failures. The total cost for changing those four parts was estimated to €800. During those damages the water company was alerted but they have not experienced any shutdown time for the system.

Because of the proved usefulness and reliability of the installation in operation expansions and upgrades for the system are planned and strategic decisions have been made based on data provided by the system.

3. Applied technology

The innovation produced in this work is the reliable technological mixture of WiFi wireless network, web i/o logic controllers and custom SCADA application at low cost. The total budget of the project was €100.000. For the same results other technologies can be used such as the usual private/public landline or cellular or satellite

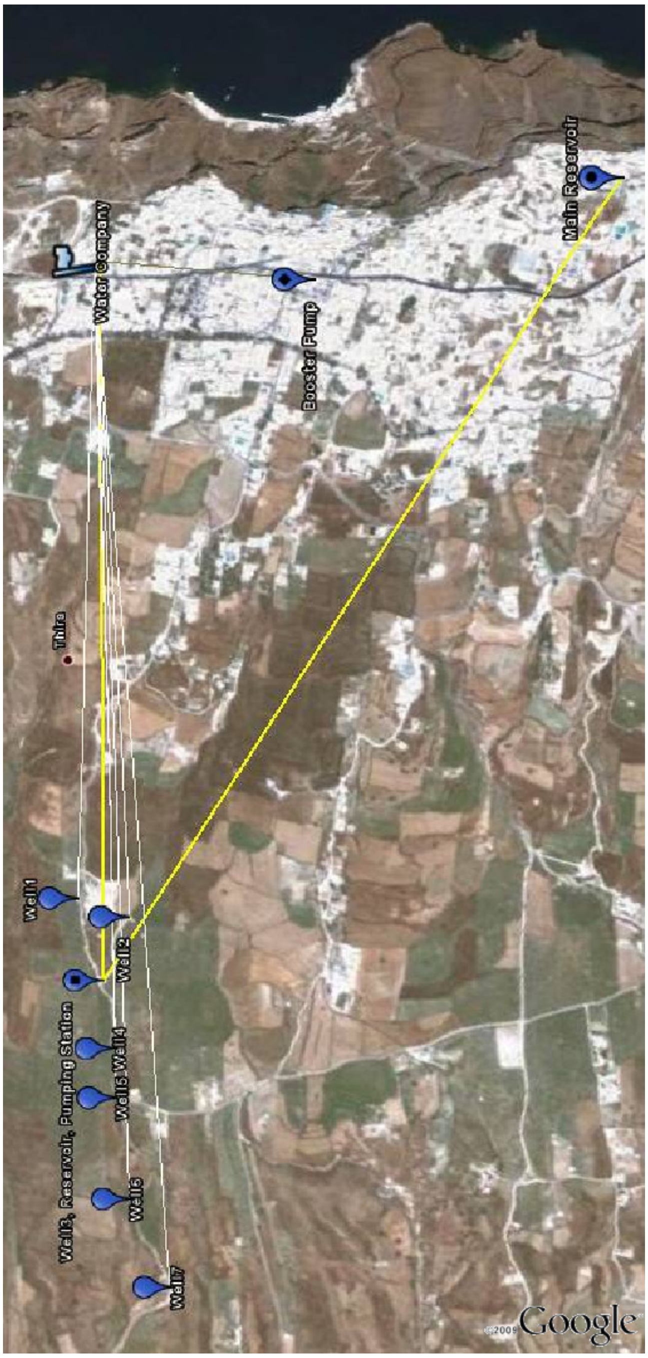

Fig. 1. Site map and WiFi network connections in Google Earth..

or vhf/uhf transceiver network, combined with PLCs and standard SCADA software packages. However, the main advantages of the applied mixture of technologies are flexibility, reliability and the lower cost in comparison to the other standard solutions.

3.1. Network

In a previous work [15], the deployment of a WiFi network for SCADA communications was described. It was shown that the planning of such a network requires GIS analysis for the sites, in place measurements using low cost equipment and some mathematical analysis to estimate the effectiveness of the proposed solution. It is almost sure that despite the depth of the theoretical analysis, RF propagation can not be completely calculated so that fine tuning of the network is required during the installation.

WiFi networks have been proved reliable for the past five years to securely interconnect computers, fast and at low cost for small businesses, households and even among buildings in big companies. Using WiFi networks for 50–100 m range solutions are a secured success. For longer distances up to 40 km line-of-sight is required. Line-of-sight can be described as a virtual empty tube, whose radius is distance depended; connecting the two sides of sites which are about to be connected. If obstruction occurs in more than 30% of this virtual tube then the connection will be unreliable, so other options or another helper site should be found. When a WiFi network is reliably working, data rates from 1 to 54 Mbps will be available, so that not only SCADA data but even streaming video and audio from the sites can be available using IP-cameras.

To evaluate correctly WiFi networks a brief consideration of some aspects should be done. The range of a WiFi network is limited to 40 km when line-of-site exists. When line-of-site is not possible or for more than 40 km repeater antennas should be placed in suitable locations to expand the network coverage. So coverage and range is a design feature that can be modified according to the needs. The problem when repeaters are needed is the availability of the field or the existence of a suitable public place to install the antenna. Sometimes repeaters has to be installed on the top of a mountain so solar powered repeaters and lightning protection could cost up to five times the repeater cost. SCADA applications usually utilizes up to 50 Kbps of bandwidth. The minimum available of 1 MBps in WiFi is securely twenty times over the required one. WiFi security is considered scalable because there are many scalable ways to lock a network from intruders. MAC address access policy and WPA-PSK encryption are considered strong security measures for a WiFi. Firewalls of course protect the SCADA PC. Beyond the cost of deployment WiFi network will return its value because it will work for several years and the company will pay only a very small power bill for the 10 Wt consumption per antenna.

3.2. Web i/o

I/o modules are available in the market and they are simpler than PLC's providing simple autonomous control or to other modules through network. ADAM-6000 series produced by Advantech are web i/o modules providing basic control as described and option to be controlled over network with at least the following ways:

1. Through their Java web based interface
2. Through Advantech's ADAM.net application
3. Through any SCADA application using OPC server
4. By a central controller ADAM-6501 module
5. By a custom written application using com objects or .net programming classes

There are several ADAM modules capable to measure enough signals and provide enough outputs. The basic idea to use ADAM 6017 modules to control wells, pumps and reservoirs, as well as desalination plants and many other installations, is that breaking up the problems to up to 8 signals and two binary actions would be very helpful to make a clear modular design and avoid the risk of massive failures. In addition; it is more than enough for water management applications to measure less than eight signals at every point. In a well for example in this work there are three (3) currents to be measured for the pump, a thermal protection status and the water pressure, flow and conductivity. In addition the required control is one output for the pump to start and stop. For wells an autonomous control can be accomplished, when the device looses network connection to SCADA for time over 30 s. The module can stop the pump unless network connection is able to provide information about the level of reservoir that this well is filling. The SCADA application which lost the network part of a particular well would send an SMS message to authorized personnel.

For bigger installations such as a desalination plant it is estimated that four (4) ADAM 6017 modules would be enough to provide SCADA enabled control for all the parameters of the plant. This type of modules are capable to lower the budget of a project not only because of their low cost (€250 each) but also because of their flexibility, easy installation and configuration, needing less manpower than other solutions.

3.3. SCADA software

The SCADA software used in this solution is a custom written VB.Net application using ADAM.Net classes and Microsoft SQL 2005 database server. It is designed to provide all the information for the status of the sites immediately; with four status colors for each signal (Fig. 2).

The measured parameters for each installation can be also seen in Fig. 2. This software is a multithread application working in six independent threads and exchanging data between each other. The interface is simple but very informing and the log analysis/report system can provide graphical display of signals over time. All configurations are made by filling values in tables and there is option to manually (semi automatic–only alerts) or automatically operate the system. Colors other than green in signal names display problems in measured values or network. Important messages are displayed at the bottom of the window.

During power failures personnel is alerted in case UPS battery does not last enough time. The application is monitoring itself for failures during which might close and sends notifications. Another application is also monitoring computer performance and the main application in order to notify developers for errors and authorized personnel during failures.

The PC running SCADA application can be remotely managed through internet anywhere in the world, so notifications and alarms can be evaluated by authorized personnel even at home.

3.4. Protection

Reliability in SCADA system can be achieved by minimizing all factors that can cause network and signal acquisition interruptions or software malfunctions.

1. In a SCADA system like this, constant network operation is crucial, so every part of the network design should be rock solid.
   - Masts holding WiFi network equipment should be really stable in extremely windy conditions, easy to access for repairs and safe for people working on them.
   - Network devices should be safe from cold, heat and moisture either by the manufacturer or using IP65 boxes with proper airflow.
   - Antennas should be stable and strong against corrosion. Radio frequency cables should be protected from electrostatic discharges and lightning with proper lightning arrestors.
   - Network cables should be shielded and properly protected from fields during thunderstorms using surge arrestors in both ends.
   - Further more all network devices should be easy to configure and install during repairs.

Lightning fields is the most serious danger for network equipment and can be avoided by proper grounding, shielding and by using surge arrestors. Still grounded masts in high heights are easy targets for lightning. To avoid a direct hit on the vulnerable masts, another mast should be set in about 80 m radius and at least 5 m higher holding an early streamer ionization lightning rod to attract lightning in a more efficient way than the network mast. But even if a part of the network is lost, this part should have the ability to understand that central control was lost and to produce specific actions to prevent damages.

2. Signal acquisition should happen within specific time intervals. Signal acquisition should not be stopped during power failures and a UPS in every site would secure that. Sensors that fail should be automatically removed from the inputs of the i/o module to pre-

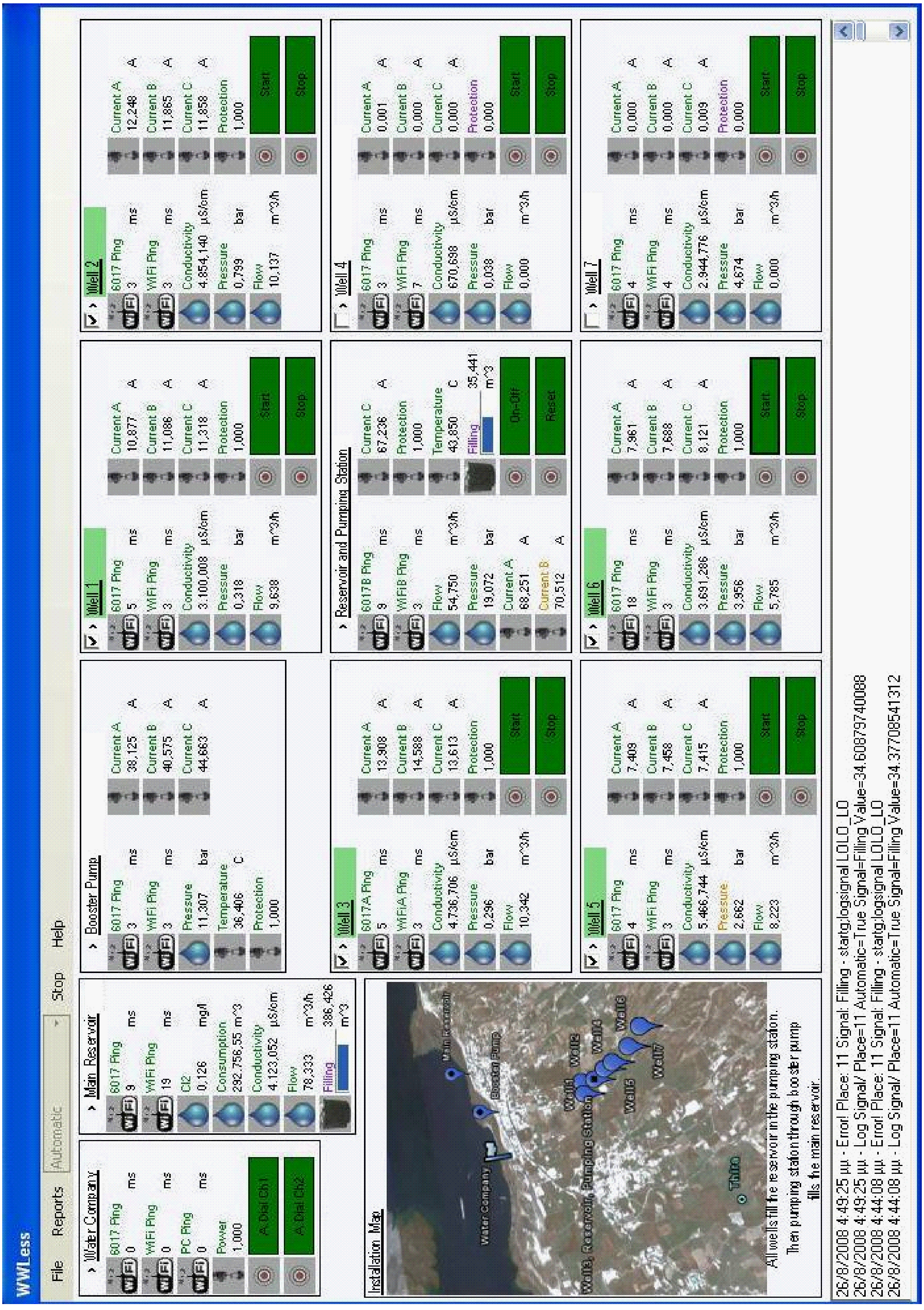

Fig. 2. SCADA application.

vent damage or conflicts on other signals. This can be achieved by proper fusing and surge protection circuits. I/o modules and sensors should be easy to configure and replace in case of an incident.
3. SCADA software should be written in a very clean way avoiding complicated parts in a single procedure. Multithread design of the application would help speeding up each process and breaking logic to smaller and easier parts. Stable operating system and database server would help on producing a stable SCADA. The application should have the ability to manage circumstances like network parts downtimes and proceed to actions based on process importance. Multiple ways of communication with personnel can provide a fail-safe alert system. A SCADA monitoring application to detect PC or program failure should exist. Error reporting and application on-line update system can provide fast response from the developers.

Fig. 3. ADAM 6017 and simulation boards.

4. Principles of automation

In this solution there is the main reservoir whose level starts/stops the pumping station in the small reservoir and the booster pump. The smaller reservoir's level starts and stops the wells in a sequence that is calculated by algorithm taking into account the water quality through conductivity measurements and well/pump stress through working hour's measurements. Power failures or thermal protection status failures disables a well, so that the system is not trying to use it. Authorized personnel can be alerted through phone call, SMS or email for low or high reservoir levels and other important signals out of preset points. Even power supply asymmetries can be displayed. Usually one outranged signal triggers an action. For actions requiring combined outranged signals, it is enough to trigger the action from just one of the outranged signal and then a check for the combination is done before performing the action. Using a programming language to perform automation it gives the developer endless possibilities.

5. Software development

For software development it is necessary to have at least two web i/o modules in a network and two simulation boards for signal inputs and outputs as it is illustrated in Fig. 3. The application can be designed in small parts that can work for a simple problem involving two sites each time and then it can be configured for all sites and work similar to the two site problem.

A simple and clean database was designed for such an application which can provide robustness and easiness in development and maintenance (Fig. 4). The database holds:

1. [Places] table in which sites are described.
2. [Signals] table in which signals are described for each site.
3. [SignalTypes] tables in which signals are categorized for look and feel purposes.
4. [Alarms] table in which manual and automatic limits and time delays as well as named actions are held for each signal.
5. [LogTable] table in which all signal values are logged.
6. [AutoPump] table holds the settings, to automatically select the wells that should be started or stopped.
7. Finally another table for configurations exists to hold several program parameters.

SCADA application is designed as a multithread application (six threads work) doing independent loops exchanging data each other:

1. Controller thread that holds the application up and running
2. Read signals and convert the electrical values to physical
3. Check network status
4. Make the comparisons between the signal values and the error levels adjusted and decides for actions
5. Log signals to the database and reload settings every 10 min
6. Provide the changes to the graphical interface and get user actions.

Signal conversions can be linear or described by a function. Actions are simple functions like: start or stop pump, call phone, send SMS, send email, log signal set a well enabled or disabled for automatic use.

6. Installations setup

The installation of such a system requires careful planning of the network and analysis of the current situation.

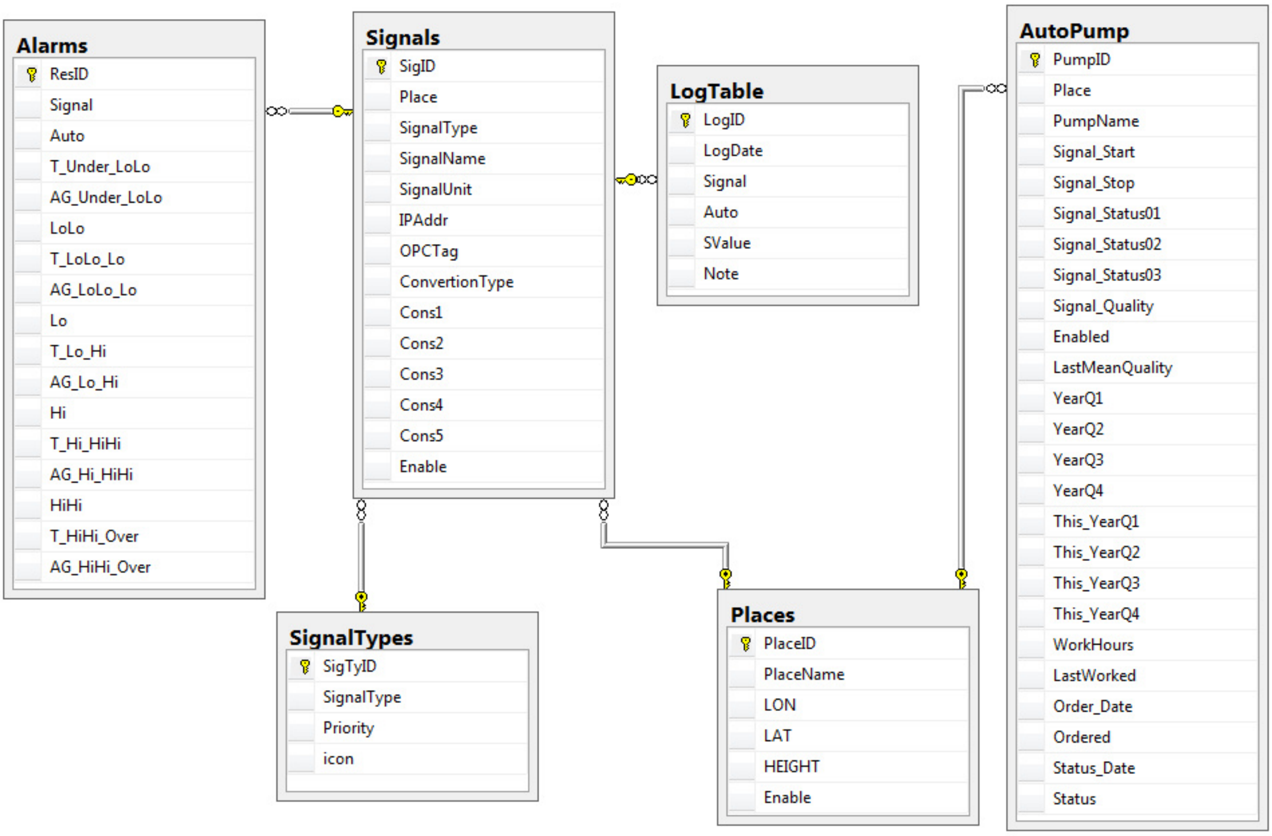

Fig. 4. Database design.

Planning will provide a list of materials and constructions which are needed in each site. The steps to materialize the project are:

1. Construction of masts, automation and network panels (Figs. 5–8).
2. Install and setup PC, antennas and network (Fig. 7).
3. Install and setup automation panels and connect the web i/o on the network (Fig. 8).
4. Install cables and adjust sensors and outputs to the web i/o modules.
5. Calibrate SCADA's conversion functions to provide measured values out of electrical signals.
6. Fine tune network, web i/o modules and sensors while working in manual mode.
7. Adjust error levels and actions for automatic mode.

Fig. 5. Main antenna tower over water company.

Fig. 6. A typical antenna mast in a well.

Fig. 7. Network panel and antenna. 1: WiFi transceiver, 2: power supply – surge arrestor, 3: cooling system, 4: fusing, 5: network panel cooling, 6: lightning arrestor, 7: antenna.

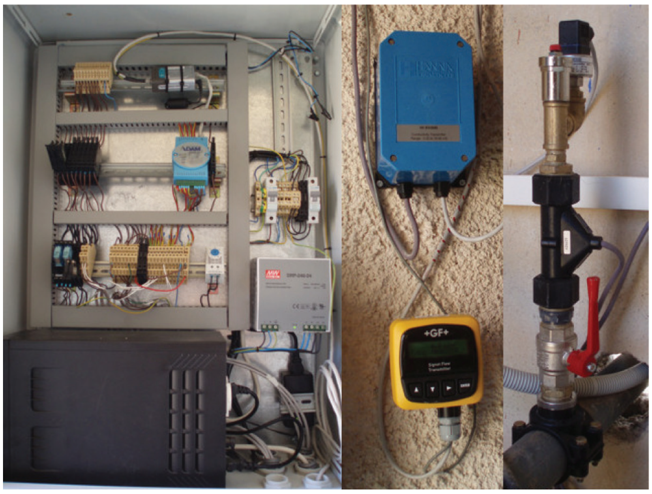

Fig. 8. Automation panel, instruments, sensors. Left: Automation panel contains: UPS, power supply, fusing, web i/o module, relays, surge arrestors and cabling. Middle: Instruments. Right: Sensors.

7. Results and discussion

The expected results, after the installation of this system were:

1. The achievement of automatic constant operation of the water supply system in the area of Fira without personnel involvement on the procedure.
2. To get almost in real time (5 s delay) measurements of the water quality of the wells and reservoirs, through the conductivity of the water and the chlorine concentration. Previously only samples could be taken periodically and a great gap of information between values existed.
3. Achieving quick fault finding during damages and malfunctions of electromechanical systems.
4. Log analysis of the quantity and quality of water, provided information used in strategic planning of investments for the water company. Water company is building a desalination plant to improve the water quality from the seven wells. Water company is also trying to expand the SCADA system and the network to other sites and installations.
5. In time alert of authorized personnel minimized damages in incidents happened.
6. It was expected that water quality would be improved because of the management of the wells. This actually happened during winter; see Fig. 9 in which not all wells were necessary in operation at the same time. Instead during summer all wells had to work so SCADA did not have any real option to prioritize some of the wells in order to improve the quality.

   In Fig. 9 the water conductivity in the main reservoir is displayed. From the end of October until the end of November it was the manual trial operation of the system. Then during the automatic operation the quality keeps improving faster than before until the end of January during which the well No. 5 became available to the system. Water coming out of the well No. 5 was really poor in quality and this affected the overall conductivity. Still the system was able to adjust and improve the quality once more. From March the demand increased and all wells had to be used so the quality went worse and over the limits set by EU for potable water.
7. Preventive maintenance. For example any increase in the currents of the pumps indicates an oncoming malfunction or complete destruction of the pump which can be prevented. That was noticed in well No. 3.
8. Redundancy was not required in that system and it was limited to:
   - Uninterruptible power supplies for one our of power failure.
   - Double SCADA PC and software in case of a hardware failure (unplug the failing system and plug the other).
   - Set up rules in the telemetry modules to stop pumping in sites with an extended network failure.
   - Early warning system in a potential failure.
   - Multiple ways to alert personnel.

   Redundancy is possible and would cost more for the company. The option of having spare parts in the storage room and the existence of an early warning system costs much less. However redundancy would be:
   - Off grid photovoltaic power supply in every site.
   - WiFi mesh with alternative paths to have a stable alternative network in every case.
   - Double PCs running SCADA with data syncing and automatic control transfer among them or run-

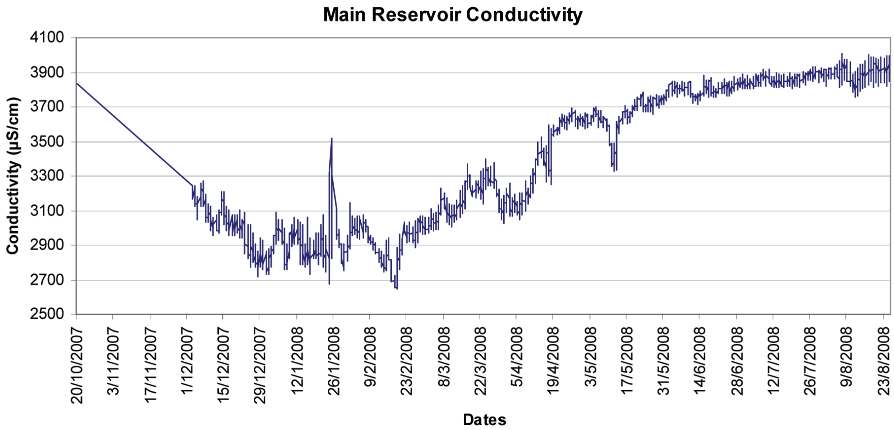

Fig. 9. Water conductivity in the main reservoir.

ning the application in a cloud computing system.
- Set up rules in the telemetry modules to work with or without getting commands by SCADA software.
- Early warning system in a potential failure.
- Multiple ways to alert personnel.

9. Burglary has not happened because the installation is set up in an island and there are two ways to leave the island, either by boat or by plain. So nobody would attempt to steal something because eventually would get caught. Stealing an antenna would alert the personnel because the site would go off line. Telemetry modules in most places provide more inputs than we use. In the "empty" inputs we could easily connect low cost magnetic contacts, or motion sensors like the ones used in alarms to be able to monitor when a door/window is opening. Also as mentioned in the paper the bandwidth is enough to provide as streaming pictures from a web camera in case we need to install some for antitheft purposes.

8. Conclusions

In this work a comprehensive water management system was designed and installed in the area of Fira of the island of Thira in Greece. The benefits of a water resources management system as the one described in this paper are:

1. Automatic usage of the water resources based on quantity and quality of water, which protects the resources and can improve the overall quality of water.
2. Constant quality and quantity control.
3. Secure remote management of the SCADA application through internet.
4. Quick fault finder tool for in time diagnosis of problems and fault patterns and the application of preventive maintenance.
5. Constant logging of values which helps the strategic budget planning of the water company.
6. Logged signals can be connected to an ERP software to dynamically estimate the water cost.
7. It helps reduce costs in maintenance and human resources.
8. It can work side by side to an existing automation as a main or backup solution adding SCADA capabilities.
9. It can be easily installed, maintained and expanded.
10. It uses simple low cost technology.
11. It can operate either using a PC as a controller or a controller module.
12. It can be installed in areas which are not easy to reach and it can be completely autonomous even from power supply by using solar power.

It can be concluded that this work presents a rock, solid, reliable and low cost solution for the water management of remote water resources when it is carefully planned in network design and correct selection of materials are made.

Acknowledgements

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