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Improving existing monitoring systems in six dams by automation and central data management

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Abstract

In the period from June 2012 to April 2014, SISGEO S.r.l. completed an important project focused on the rehabilitation of existing monitoring systems in six dams owned by JSC Macedonian Power Plants (ELEM), all located in the Republic of Macedonia. The first four rockfill dams, namely Mavrovo, Spilje, Globocica and Tikves, were constructed between 1952 and 1969. The manual instrumentation in the four dams was, to a large extent, the same as originally installed and, due to careful maintenance, the instruments were still in good condition. The Kozjak rockfill dam was commissioned in 2003, whereas the Sveta Petka concrete arch-dam was commissioned in 2012. Both dams already had a local automatic monitoring system that was in very good condition. Nevertheless, ELEM wished to have a centralised monitoring system for the abovementioned dams. The purpose of the project was therefore to automate, to centralise all the existing monitoring system and to create a central data management unit in the ELEM facilities located in the city of Struga.

For first four dams, the automation was performed for the existing instruments, i.e. piezometers and seepage weirs. In the more recent Kozjak and Sveta Petka dams, the main activity was to complete the automatic system by installing sensors in the existing open piezometers.

Furthermore, additional activities have been performed, such as replacement of existing seismic equipment, implementation of video-surveillance system in galleries and implementation of pump working time measurement. At each dam site, a formal data transmission system has been implemented, mostly utilising existing fibre-optic connection. Wherever this fibre-optic connection was not available, a GSM-GPRS based transmission system was added.

All dams are thus included in the central data management software, which has been specifically designed for the project. Local monitoring units at each dam site have been implemented, all sensors have been identified via a barcode system, and readout units have been provided to dam wardens. The system allows comparison between readings taken automatically and manually. A specific overvoltage protection system has been implemented as well, taking into account the specific geological conditions, the sensor location and the cable path.

This paper gives an overview on the complex project, underlining the main difficulties faced and solved during the work progress.

1 Introduction

JSC Macedonian Power Plants (ELEM) owns and operates eight hydropower plants in the Republic of Macedonia, located in south-eastern Europe, with a total installed capacity of 528 MW. The hydropower assets include the five clay core embankment dams (Mavrovo, Spilje, Globocica, Tikves and Kozjak), and the Sveta Petka concrete arch dam. A location map of the dams is given in Figure 1; salient features of the dams are summarised in Table 1.

Figure 1 Location map of the dams belonging to ELEM

Table 1 Salient features of the dams belonging to ELEM

	Name	Type	Year completed	Height (m)	Crest length (m)	Dam volume (10^3 m^3)	Reservoir volume (10^6 m^3)
1	Mavrovo	Rockfill	1952	54	210	777	357
2	Spilje	Rockfill	1969	101	330	2,699	520
3	Globocica	Rockfill	1965	83	196	998	58
4	Tikves	Rockfill	1968	104	338	2,722	475
5	Kozjak	Rockfill	2004	114	300	3,340	550
6	Sveta Petka	Concrete arch	2011	69	118	27	9

The monitoring instrumentation in the first four dams is, to a large extent, the same as that originally installed more than 40 years ago and, due to careful maintenance, most of the instruments are still in good condition. However, some components, such as the readouts for the cells measuring the pore and total pressures in the dam bodies and the seismic monitoring equipment, were outdated. ELEM commissioned a project for the rehabilitation of the dam monitoring instrumentation. At the same time, a comprehensive programme for the automation of the instrumentation and transmission of the monitoring data to a central monitoring centre for all dams under ELEM's responsibility was initiated. The transmission of the monitoring data also included the most recent dams being Kozjak (commissioned in 2004) and Sveta Petka (commissioned in 2012), which were already equipped with an automatic dam monitoring system.

The project also included additional activities, such as implementation of video-surveillance system for galleries and pump operational time measuring devices.

The work at Sveta Petka started in June 2012 and everything was completed in April 2014, after a comprehensive training on utilisation of portable dataloggers and software for data management.

2 Instrumentation installed

2.1 Existing instrumentation

The existing instrumentation consisted of:

- Open piezometers measured by means of portable water level indicator.
- Piezometers under pressure located in the galleries and measured by means of manometer.
- V-notch weirs for seepage, where level was measured by staff gauges.
- Vibrating wire pore and total pressure cells, installed more than 50 years ago, measured by portable read-out.

2.2 New instrumentation

The newly installed instrumentation is reported in Table 2:

Table 2 List of new instruments installed

Sensor	Mavrovo	Spilje	Globocica	Tikves	Kozjak	Sveta Petka	Total
Open piezometers	42	44	19	34	18	22	179
Piezometers under pressure	9	37	35	3	–	–	84
Seepage water sensors	8	19	15	8	–	–	50
Water level sensor	1	1	1	1	–	–	4

In total, more than 300 new sensors have been installed.

2.3 New sensors

For the automation of open piezometers, a vented pressure transducer has been selected to provide automatic compensation of air pressure variations. Each transducer was placed into the piezometer casing at the depth of 5 m below the minimum recorded level. Some of the existing piezometer casings were clogged, which necessitated a new installation depth.

Vented pressure transducers were also selected for the automation of measurement of the water level in the reservoir. The installation of such instruments was difficult, and in order to install the sensors 5 m below the minimum reservoir level, it was necessary to employ professional divers who carried on the job in the winter period (Figure 2), when the level of the reservoir was at the minimum. There were no alternatives, since the visibility in the lake at depth of over 6-8 m was not suitable for the installation works.

Figure 2 Divers for installation of water level gauge in the reservoir

The piezometers under pressure, mainly located in the galleries, have been automated by means of vibrating wire pressure transducers. The hydraulic connections have been replaced as well in order to fit the new transducers (Figure 3).

(a) (b)

Figure 3 Automation of existing piezometer under pressure (a) and of seepage weirs (b)

Pressure transducers have also been installed in seepage weirs in order to allow automatic readings of water level (Figure 3) and to obtain the water discharge by specific formula. The pressure transducers were equipped with special rods to allow for positioning under water. In some cases, especially in the galleries, the weir was completely rebuilt, as there was no other choice than to do it manually because of difficult access to the lower part of the galleries.

Once the instruments were installed, the major problem was to lead the cables to the control room of each dam site, where the automatic datalogger has been located. In total, more than 20 km of different types of cable (from two wire signal cables up to 32 wire multicore cables) have been installed for the six dams. The cables have been mostly laid in trenches or, alternatively, in specific conduits, especially in such locations where soil condition (e.g. rock, excessive slopes etc.) prevented open trench excavations (Figure 4).

Figure 4 Trenches and manholes for sensor cabling

Manholes have been installed along the way to allow inspection of the cable paths and future maintenance on the cabling system. While building the manholes, particular attention was paid to the drainage of the water, ensuring that the cable and the junction boxes are in dry conditions.

2.4 Portable read-out and dataloggers, hand-held field computers

To allow manual readings of newly installed sensors, a portable datalogger has been provided at each dam site and is required to read both vibrating wire and 4-20 m signals coming from different types of pressure transducers. In those dams where old vibrating wire pore and total pressure cells were installed, the previous read-out units were outdated and thus replaced with new ones. Moreover, the old switch panels were not in good condition; therefore, they have been replaced by new ones. At this step, it was also agreed to reconnect only working instruments.

Figure 5 Example of barcode labels

The hand-held field computers have been programmed to allow:

- Identification of the instruments with the barcode reader (Figure 5).
- Receiving the manually read value of the corresponding instrument (input via keyboard).
- Storage of the keyed-in value together with the actual date and time.
- Interface to the local data processing centre to download the collected data and incorporate it into the database for the corresponding dam.

When receiving the manually read value, a plausibility check of the newly read data is carried out, either with the help of a statistical correlation based on historical data or by implemented fixed threshold values. The statistical correlation has been implemented mainly for the piezometers.

Specific training was implemented for all dam wardens so that they would be familiar with the new equipment.

2.5 Automatic dataloggers

The core of the system is represented by an automatic data acquisition system (ADAS) installed at each control room. The ADAS units are designed to power the sensors, receive, store and transmit the data to the central control station (Figure 6).

The local control rooms are connected to the central control station, forming a client/server architecture that provides the services of recording, processing, visualisation and analysis of the monitoring data. In particular, the local data processing centres:

- Allow data from the individual instruments or from instrument groups to be displayed in graphic and numeric form.
- Summarise data from the individual instruments or instrument groups in long-term graphs or numeric tables.
- Allow the display of alarms when readings from selected instruments reach or exceed specified values.
- Allow the manual input of data and the download of data from the hand-held field computer (used for manual readings), and from the portable datalogger.

It is considered essential to have these functions decentralised at the dam site and to leave the responsibility to the dam warden. It is the warden’s duty to regularly check the incoming data from the automatic instruments, to compare it to manually read data and to administer the database.

Figure 6 ADAS installation in the auscultation room

Specific dataloggers for existing pressure cells have been installed, configured and connected into the system.

The connection between the dataloggers and the central data processing system utilise the existing ELEM fibre-optic network. In two dams (Mavrovo and Globocica), this network was not available; therefore, a GSM-GPRS based data transfer system has been implemented by means of two industrial modem routers capable of sending the data directly to the central server.

2.6 Overvoltage protection and grounding system

On 16 August 2013, 24 of the instruments installed at Globocica Dam (mainly seepage sensors and open standpipe piezometers) failed simultaneously. In December 2013, it was also discovered at Spilje Dam that A total of 17 open piezometer instruments and 11 seepage measurement stations failed simultaneously. Investigation of the failed instruments back in the factory revealed that only the electronic boards were damaged, while the sensors remained in good condition. This led to the conclusion that the damages were caused by overvoltage running along the cables. In the case of the Globocica Dam instruments, the overvoltage was attributed to lightning from a thunderstorm that was observed in the area that day. In the case of Spilje Dam, it was concluded that the overvoltage was caused by the powerhouse, which is located close to a main duct of signal cables.

Similar problems also appeared in the Kozjak and Tikves Dam sites, although on a limited number of externally installed sensors.

The failures occurred despite the standard transient protection incorporated in the equipment, comprising of:

- Level transducers installed for seepage measurement stations. The sensors are isolated by an oil membrane that provides a voltage isolation of up to 500 V.
- Pressure transducers installed in open piezometers.
- The sensors are encased in a ceramic membrane that provides voltage isolation of around 2,000 V.

Additionally, each data acquisition unit provides gas discharge tubes (GDT) on all inputs of the signal cables.

No damages were recorded in vibrating wire instruments or in the data acquisition units, except one multiplexer board that was burned out at the Tikves Dam site. In order to better protect the instruments and to avoid future failures, the following measures have been agreed on and implemented in all dam sites:

- Additional overvoltage protection (OVP) in all junction boxes, which are located close to an instrument.
- Connection of the OVP by copper cable to a metallic part, e.g. existing piezometer casings or V-notch plates.
- Replacement of the conventional cables running close to the powerhouse by fibre-optic (FO) cables, which are not affected by electrical noise, and installation of additional dataloggers to connect to the FO cables.
- Connection of the protection system included in the ADAS unit to a proper grounding system.
- Connection scheme for the shield wire for the signal and multicore cable. The shield wire for the cable coming from the sensors was connected to the OVP, while the shield wires of cables running toward the ADAS were not.

The implementation of additional overvoltage protection and the grounding system required the checking of all connections in order to comply with the agreed scheme.

An example of grounding system for an external sensor is shown in Figure 7.

Figure 7 Overvoltage protection for external sensor

2.7 Additional systems implemented

Besides the rehabilitation and the automation of the monitoring system, additional activities were included into the scope of the works as follows:

- Replacement of seismic equipment.
- Video-surveillance system.
- Pump operational time device.

2.7.1 Replacement of seismic equipment

In Mavrovo, Spilje, Globocica and Tikves Dams, the existing seismic equipment was outdated. The layout typically comprises of three instruments in the highest dam cross-section along the downstream face (one instrument at the dam crest; one at mid-height; and one at the dam toe) as well as one instrument at some distance from the dam to record the free field acceleration. New accelerometers have been installed in the same positions and connected to a data recorder located in the auscultation room at each dam site. The data recorder is able to automatically record those events, which overpass a specific trigger level and send the relevant data file to the centralised data system.

2.7.2 Video-surveillance system

A total number of 34 infrared video surveillance cameras have been installed in the dam galleries (Figure 8) plus one outside at Tikves Dam site. They provide monitoring from a computer terminal situated in the local auscultation room. A still picture is taken from each camera every 12 hours and stored on the computer's hard disk. In addition, the still pictures are sent via the data transmission system to the central control Station (in the city of Struga).

Despite the cameras being the infrared type, the quality of the pictures taken in the galleries was not ideal. A significant improvement in image quality was achieved by switching on the gallery lights. The contractor therefore implemented a facility to manually switch on and off the light from the computer terminal situated in the local auscultation room. In addition, the light was switched on and off automatically when taking the still pictures.

The cameras are connected via Ethernet cable to switch boxes, and connection from switch boxes to the auscultation rooms is implemented with fibre-optic cable. The images and the pictures are stored into a dedicated computer located in the local control room.

Figure 8 Infrared cameras in dam gallery

2.7.3 Pump operational time device

All embankment dams on the project have grouting galleries within the dam body. The quantity of leakage water entering the gallery is measured by V-notch weirs and collected in a pump sump at the bottom of the gallery. The pumps are operated intermittently upon the start signal given by the level in the pump pit, and they operate until the level switch provides the stop signal.

On the power supply line of the pumps, a digital multimeter has been installed to record the amount of time that electric power is used for operating the pumps. Based on the mean pump capacity within the operating range and the measured time of pump operation, the amount of leakage water pumped out is determined. A daily value (volume of water pumped out in 24 hours) is stored in the database.

In the long term, the data series will allow the detection of any increase or decrease in the quantity of leakage water. Comparisons made to the reservoir water level and precipitation measurements might indicate dependencies. In addition, the comparison of the measured seepage values to piezometers readings within the dam body will be of interest.

3 Incorporation of Kozjak and Sveta Petka Dam Instrumentation

The Kozjak and Sveta Petka Dams were completed in 2004 and 2011 respectively and were each equipped with an ADAS at the time of completion. Under the present project, the ADAS of the two dams were incorporated into the same data processing and management system as the other four dams.

The instrumentation and dataloggers for Sveta Petka Dam were initially supplied and installed by the same contractor as the present project. Therefore, they were readily compatible (Figure 9).

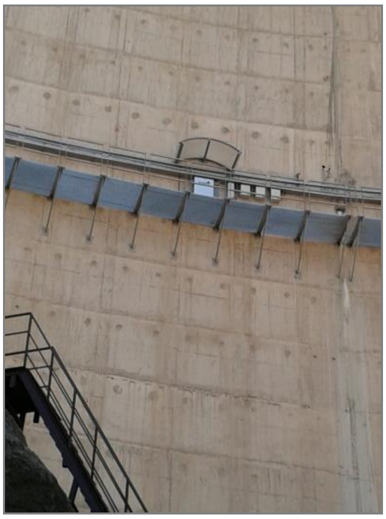

Figure 9 Sveta Petka arch dam with an existing ADAS on the downstream face

At Kozjak Dam site, the incorporation was realised by replacing the existing dataloggers with new dataloggers that are compatible with the other components of the system and connecting the existing instruments to the new dataloggers. At the same time, the hardware and software used by the dam wardens were upgraded to the same as those used in the local data processing centres at the other sites.

4 Data processing system and software for data management

The central data processing system is located in ELEM facilities in the city of Struga. It mainly consists of a server where the database and the software for data management are installed, as well as several PCs available for ELEM staff.

All data coming from the dataloggers at the auscultation buildings are managed by web monitoring system (WMS) software (Figure 10).

The advantage of such software is that it is very flexible and can therefore be tailored based on customer requirements. The users can chose which dam to enter data for, and there are several levels of user interfaces.

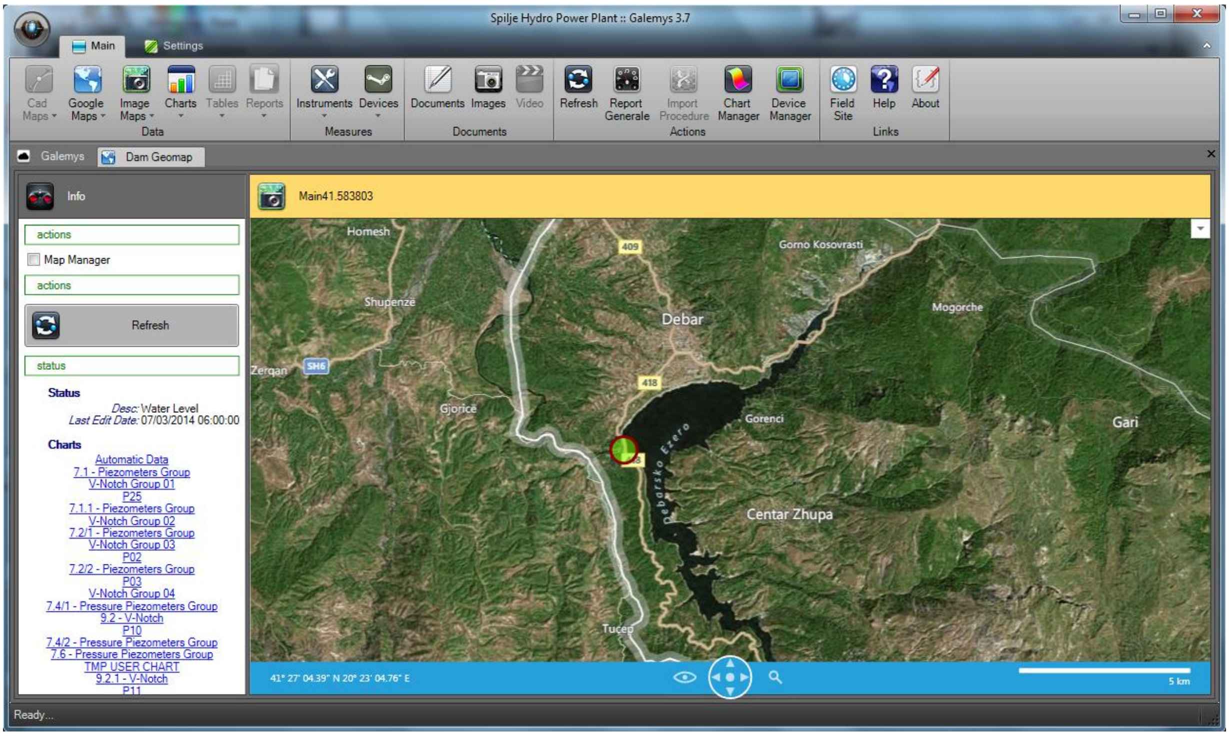

Figure 10 WMS Software homepage for Spilje Dam site

The main activity was to configure the software for each single dam site. Configuration consists mainly of:

- Creating a homepage (georeferenced), include drawings, pictures etc.
- Locating each instrument at its specific position and inputting all relevant features.
- Creating rules for data acquisition and data storage.
- Creating tables, charts, graphs for data output in for each single instruments or for different groups (Figure 11).
- Importing all existing databases and import of data coming from existing meteorological stations.
- Creating rules for management of the video-surveillance system, seismic equipment and the pump operational time device.

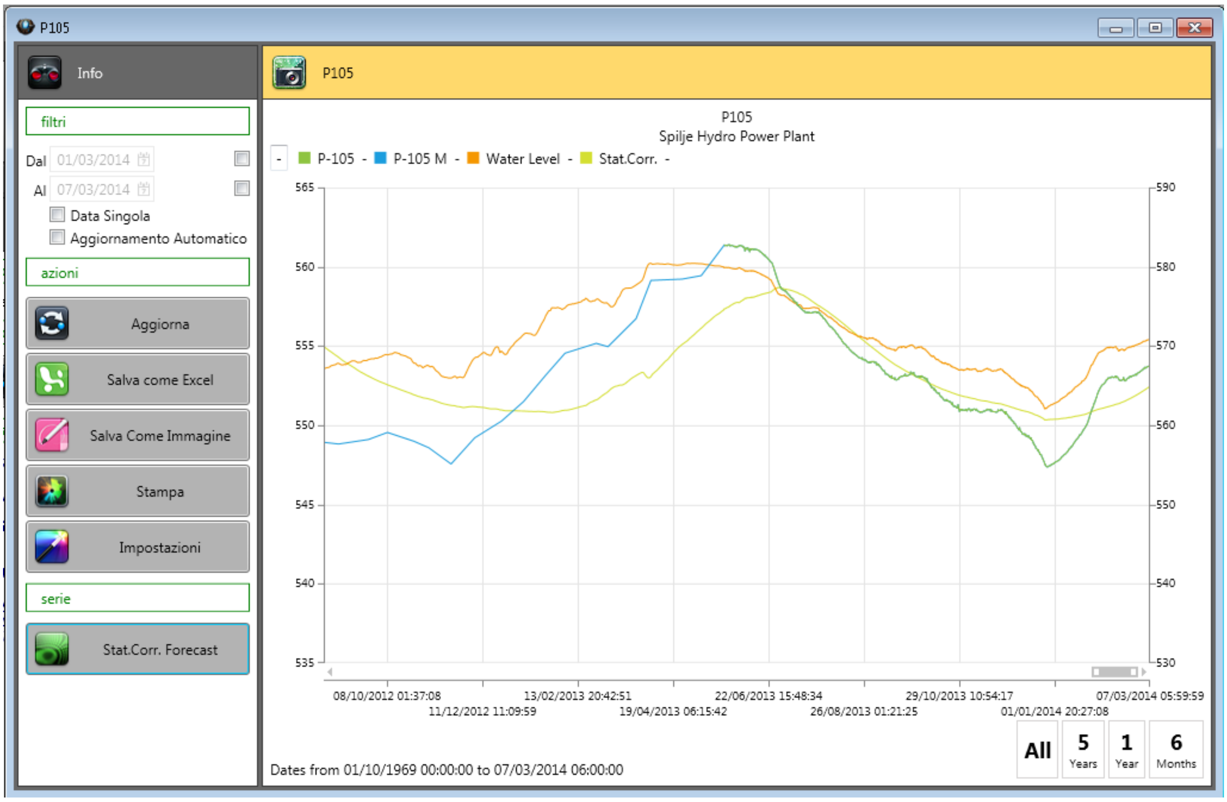

Figure 11 Typical graph for a group of sensors

A specific programming task was necessary to include the new seismic equipment, the video-surveillance system, the existing old sensors and the pump operational time device into the software. Furthermore, for some specific instruments (mainly piezometers), a statistical correlation was implemented. Thanks to this statistical correlation, it is possible to determine the expected value of some specific instruments based on the actual conditions and a correlation with earlier measurements. The calculated values are utilised for an immediate check by dam wardens, who are in charge of performing manual readings. Indeed, it is possible to compare the measured value with the expected ones.

The comparison between automatic data and measurements coming from manual reading taken with a hand-held computer is carried out in the programme in order to find any malfunction, avoiding any misunderstanding on the data.

The database also includes documentation such as pictures, as-built drawings, calibration certificates for the instruments etc.

A dedicated training program (divided in two parts) was performed. The first part was dedicated to final users, namely dam wardens, in charge of downloading the automatically recorded data, checking graphs, uploading manual data etc. Subsequently, a training course more focused on configuration of the software and data reporting was presented for to the ELEM Engineer in charge of dam monitoring.

5 Conclusion

The automation of monitoring systems in six dams in Macedonia allows the reduction of paperwork involved in dam safety monitoring and allows near real-time monitoring of dam performance. The ELEM engineering staff can concentrate more on the data analysis, as the data is transmitted and displayed automatically. The project was complex because of logistical issue such as different location of dams distributed around the territory of Macedonia and site works performed in difficult conditions.

From a technical point of view, the primary challenge was to include monitoring data coming from different systems, different manufacturers and different technologies into the same system.

Solving these challenges and the final success of the project were due to the strong cooperation between the contractor, client and consultant.

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