IT/OT Integration at Jirau Hydropower Plant: real-time operational intelligence using the PI System.

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Abstract

The operation of hydropower plants is directly linked to data from several systems. For example, sensors and actuators data are usually managed in SCADA systems, while maintenance scheduling and hydrological conditions data are generally stored in managerial applications. The systems more focused on the control level (field level) are usually referred to as Operational Technologies (OT) systems, and those focused on enterprise-level applications are referred to as Information Technologies (IT) systems. The efficient integration of IT and OT systems presents a significant challenge for industries because each system type has different perspectives and objectives. Still, it is vital to achieving the best operational performance possible. Therefore, there is a trend of studies regarding the IT/OT integration in the power and utility market, although they usually focus on transmission systems. On the other hand, in the hydropower generation market, there is typically a lack of applications that can successfully integrate and analyze data from IT and OT systems to transform such data into useful information for operation. The lack of such applications often results in manual activities to collect and analyze data and thus, reducing its effectiveness. This paper presents an architecture for integrating IT/OT systems focused on the hydropower generation market and discusses its implementation and results in the Jirau Hydropower plant in Brazil.

1. Introduction

The efficient operation of hydroelectric power plants (HPPs) requires using and analyzing information such as the river characteristics and hydrological scenarios where the HPP is installed. This information is fundamental for the generation forecast and must also be considered for asset maintenance planning. Furthermore, the HPP operators must monitor assets and process conditions in addition to operational data to guarantee meeting the predicted generation and must also duly record asset management and maintenance activities to attest to the system's reliability. The HPPs usually use several applications to deal with all this information, managed by different teams, each of which has specific complexities and parameters. The operational data, for example, are usually managed through SCADA systems that must be able to interact with sensors and actuators on the plant using different network protocols. At the same time, the hydrological and generation predictions are usually managed at specialized applications and usually stored in relational databases.

In addition to the conventional HPP operation information, another layer of complexity and new sources of information are added if the plant dispatch is regulated by a centralizer entity: the communication between the HPP systems and the regulator. In Brazil, this occurs if the plant is included in the National Interconnected System (SIN), and there must be constant communication between the HPP systems with the National System Operator (ONS) regarding the generation and assets status. This institution coordinates and controls the SIN, aiming to ensure the generation's compliance with the needs and conditions of the SIN over time.

All the above depicts the need for different systems all over the automation pyramid established after the ISA95 standard. A simplified functional hierarchy model was discussed in [1] and presented in Figure 1. In terms of HPP systems, levels 0, 1, and 2 comprehend operational data systems: mostly sensors, motors, actuators, and SCADA Systems. Level 3 consists of operations management systems, such as maintenance management, short-term generation planning, etc. Finally, level 4 systems are related to long-term generation and business planning, maintenance provision logistics, commercial and risk analysis, etc. Most commonly, systems on level 3 and above are referred to as Information Technologies (IT), while systems on lower ones are referred to as Operational Technologies (OT).

It is necessary to have the means to integrate data from all these different systems to assess the operating condition to the fullest extent properly. Therefore, connecting IT and OT systems to provide advanced data analysis and better information leads to improved decision-making.

This kind of integration has been widely discussed recently since better algorithms and data analysis techniques have been developed. For example, Lipnicki *et al.*[2] describe the use of a Test Rig built by the *ABB Polish Corporate Research Center* to study, analyze and discuss the concepts and impacts of new methods and techniques integrating IT and OT in regard to the Oil & Gas market.

The power and utility market is also facing the challenges of IT and OT integration. For example, Garimella [3] describes the integration in a utility company in India, presenting an innovative solution to Outage Management Systems, integrating SAP, SCADA, GIS, and AMR/AMI systems to better deal with consumers and maintenance teams during outage events.

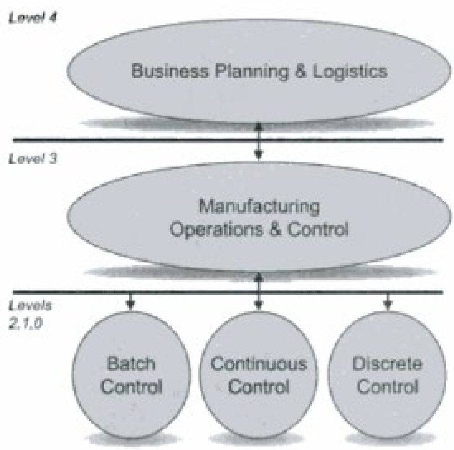

Figure 1: ISA95 Simplified Functional Hierarchy Model. Adapted. [1]

Another use of IT/OT integration in the utility market is presented in [4], where ABB Power Grids Enterprise Software uses it to optimize transmission in Germany through an Asset Health approach to their Maintenance Management program. Finally, another work that discusses the impacts of IT/OT integration on the power grid is presented in [5], where the discussion focuses on the rate of adoption of such techniques in the Swedish utility market.

Most of the literature on IT/OT integration in the power and utility market mainly focuses on transmission systems. The absence of works regarding integration in the power generation market, specifically the Hydropower generation sector, can be justified when considering the complexities of HPPs businesses and their environment. Moreover, there is a lack of tools that properly integrate many different IT and OT systems, especially in countries with centralized power system management.

Therefore, this paper proposes an architecture to allow the integration of IT and OT systems in an HPP. The architecture was developed for an HPP located in a regulated power system. In addition to the company data, the architecture must also be able to provide data for the Centralizer entity systems. The proposed system was implemented in the Jirau Hydropower Plant in Brazil, and some results are discussed.

2. Case Study: Jirau Hydropower Plant:

The Jirau HPP is located in the Madeira River Basin, 120km from Porto Velho, Rondônia, and its installed capacity is equal to 3.750MW using 50 bulb turbine generating units (GU) of 75MW each. These numbers make it the 4th biggest Brazilian HPP in installed capacity and the larger in the world in terms of GUs quantity. The HPP is presented in Figure 2.

The amount of GUs, and consequently the amount of data collected from them, presents a significant challenge for the operation, especially because this number of GUs also results in a significant amount of complementary systems and equipment. All data collected from sensors and actuators in the plant is directed to a SCADA system and stored in a relational database.

On the other hand, the maintenance data is managed through an ERP system that sends information regarding the activities to the MES system. The MES application used in the plant is called Plant Monitoring System (SAU), and it is the main communication doorway with the Brazilian power system regulator, ONS. SAU collects different resulting data from the operation regarding assets condition and operational status, hydrological data registered during operation, a log of every event registered during the day, maintenance scheduling (following ONS planning for the whole Brazilian system), and much more information.

Figure 2: Jirau Hydroelectric Power Plant [6]

Furthermore, different systems deal with additional data; the hydrological predictions, for instance, use data collected from sensors along the river upstream and downstream; the sensor data is stored in a relational database and analyzed to calculate the predictions that allow the dispatch planning and scheduling for the plant.

The analysis of joint data from different systems and most of the communication between the applications were done manually by operators and engineers, without any automated tool. These manual operations result in very time-demanding tasks and often reduce effectiveness in the analysis since the amount of data is unreasonable for humans in real-time constraints. Finally, the generation scheduling for the days ahead and the proper real-time unit dispatch was a hard task due to the characteristics of the river (the Madeira river streams carry a lot of material that usually leads to head losses on the GUs water inlets), in addition to the number of GUs.

These difficulties in the generation scheduling and GU dispatch motivated Jirau's engineers to pursue an optimization tool for the activities, and such optimization tools need data from all the different sources presented above. Hence this was a great opportunity to develop an application to effectively integrate all the IT and OT systems from the plant.

3. Solution Architecture

The first step toward integrating IT and OT was to lay out the means to collect data from the operation easily. Jirau's HPP SCADA system didn't effectively provide historical data promptly for analysis. Therefore, AVEVA Osisoft PI System software was acquired to better deal with these issues. The PI System is a system for storing large volumes of information in a temporal form. It is an integrated software portfolio, which collects data from assets, sensors, and devices installed in the HPP, and stores this data with date and time information, allowing access to historical data, enabling information queries quickly and reliably, keeping critical operations running, and the management team aware of HPP's current status. It is also possible to query the data through Excel and provide a RESTFul service through which it can consume the data through the JSON format. Figure 3 offers a view of how the PI System portfolio performs from collecting, storing, and making data readily available for analysis. In addition to storing the plant data collected by the PLCs, the PI System offers the means to analyze the data and create formulas to evaluate expressions and thus achieve the desired result.

Besides the PI System, a modular architecture was designed and developed, where several services are performed. As plant information is spread across systems, files, and databases, the architecture offers mechanisms to integrate the data making them accessible and available when they are needed and in the format expected by the applications. Figure 4 presents the developed architecture.

The hydrological data are available on the National Water Agency - ANA website, which manages the collection of information from sensors scattered along numerous rivers, as well as rainfall data, and provides access to this data through an API from where it is also possible to consult historical data. In addition to the ANA website, the SAU stores hydrological information collected by the plant's sensors and forecast data calculated by the plant's specialists. The forecasts are stored in files, which are then imported into the systems to be consumed by the plant's employees.

The SAU system is also used to record and monitor maintenance information for the GUs and other plant equipment. It is possible to obtain data on maintenance performed, a descriptive record of what was performed in each operation, and details of scheduled maintenance to verify if such equipment can be used for generation during the GUs dispatch planning phase. The maintenance procedure must be communicated and scheduled with the ONS, which controls whether or not the operation can be carried out. The maintenance request is registered in a specific ONS system, and the communication of acceptance or rejection of the procedure is carried out through emails.

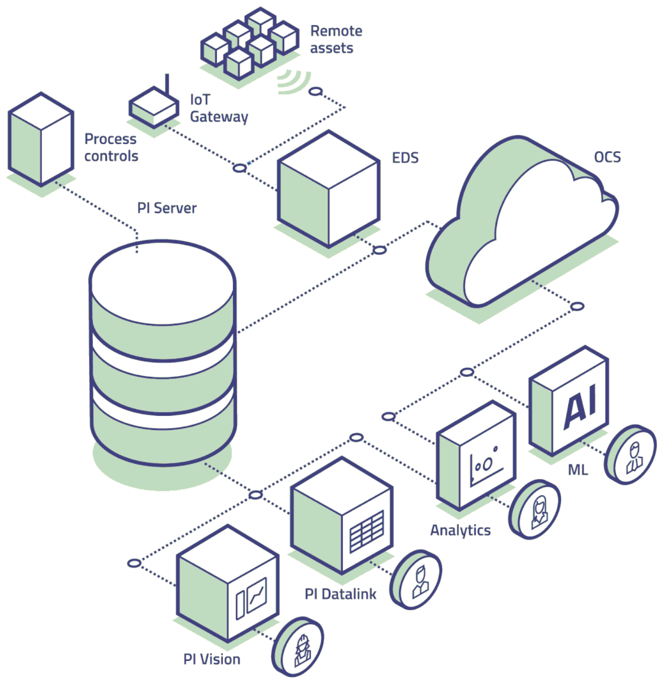

Figure 3: PI System features overview. [7]

Independent modules were created to process all the information and integrate all the services developed. Still, they communicate with each other to make the solution more robust, facilitate maintenance and allow the separation of responsibilities. These modules are included within the context of application services and comprise the tasks directly or indirectly related to the algorithm performing the unit commitment function. Along these services, there is a module for selecting the best GUs to meet the generation demand, which involves identifying the operational status of each unit. To achieve this objective, monitoring the GU status plays an important role.

The analysis of head losses plays a crucial role, given the fact that in the Jirau HPP, the accumulation of trunks and sediments negatively impacts energy generation since it accumulates on the water inlet protection grids and thus reduces the generation capacity. Therefore, identifying the progression of the dirt level and planning the ideal time to carry out the cleaning process helps to minimize the impact caused by dirt.

The optimization algorithm needs numerous input information to enable its execution. Among them is the availability of the UGs, the maximum acceptable level of dirt, the time interval between the optimization algorithm's executions, the pressure drop, and the desired throughput value for each UG. In addition to this information, information on flow, level, gross head, and the net head is also needed to enable the algorithm's calculations and allow the ideal solution to be determined within an acceptable time interval and maximize the plant's performance.

Two special modules were developed in the architecture to provide information collected from other systems, data provided by operators, and data generated by the optimization application. One of these modules offers the possibility to build customizable reports according to the user's needs, providing flexibility to the system and reducing the need for new developments by specialists since the user himself can build the reports he needs. The other module makes it possible to schedule automated exports of the information generated by the reports, avoiding the need for manual and repetitive operations. This module offers hourly, daily, weekly, or monthly export options, in addition to allowing you to add data to each export or overwrite them at each run.

The data exported by the BI integration and automatic export modules, as well as the information generated by the optimizer, are sent to a specialized Data Analytics platform, developed with the aim of processing in a distributed way all the immense volume of information produced, and making available information through specialized data visualization tools.

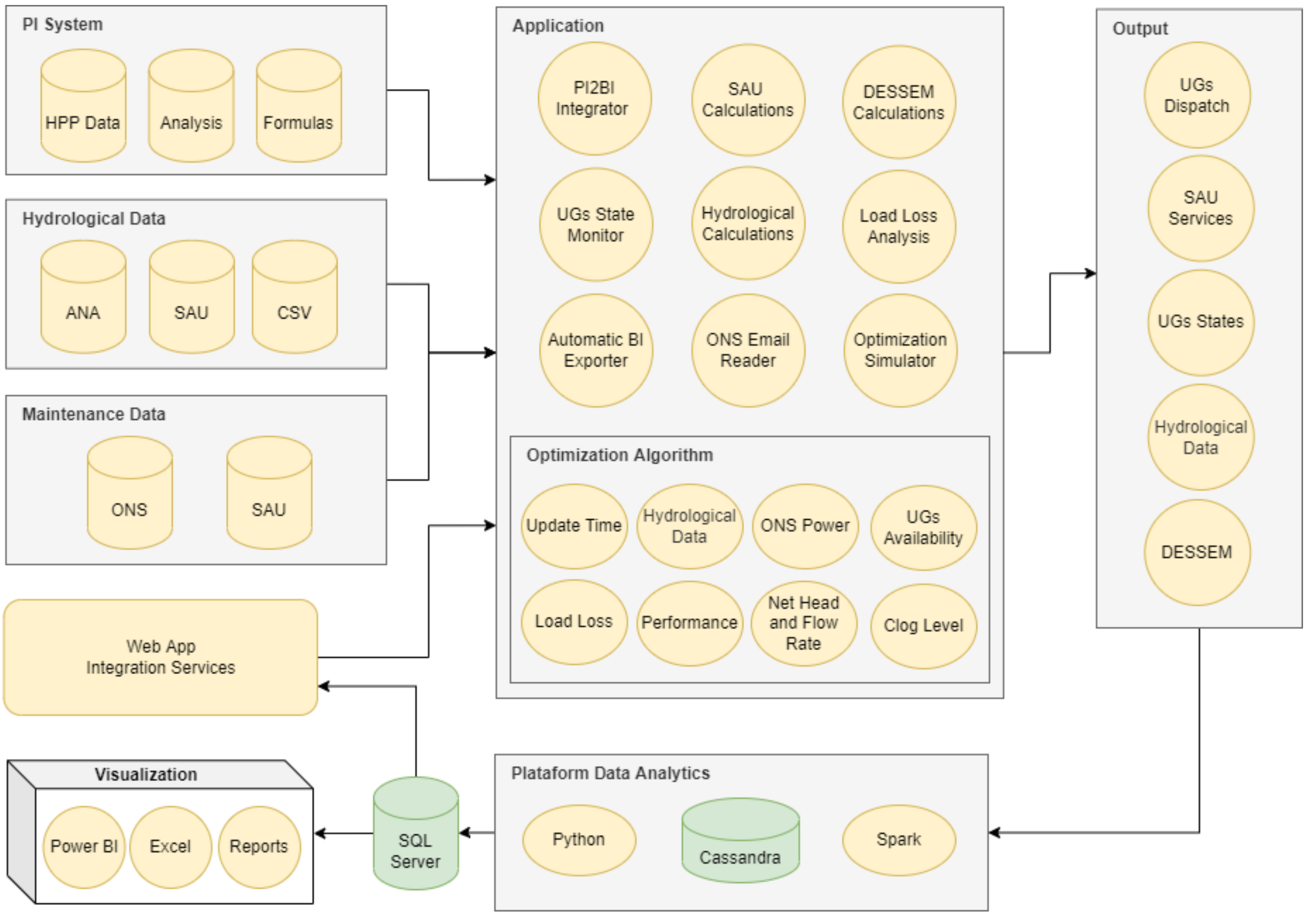

Figure 4: Architecture of the IT/OT Integration application. (Author's original).

This analysis platform was developed using Python and a framework for Big Data processing called Apache Spark. This framework manages the distribution of tasks within a cluster of computers, and abstracts from the programmer the tasks of synchronization, error management and correction, the grouping of results, and transfer of information within the network, thus allowing the focus to be on cleaning, transformation, and data processing. During processing, an appropriate NoSQL database is used to work with large data sets with non-standard formats, which performs the reading and writing of information in a distributed and performance way, maintaining the integrity and security of the stored data.

After processing, the data is stored in a BI database on a SQL Server, integrated with existing plant tools that automatically make the data available to the plant's users. The information can then be consumed using either Power BI (a Microsoft tool that enables the creation of dashboards, in addition to data manipulation), MS Excel, or even through reports created within the developed platform.

A web application was developed to enable the configuration of the various modules and view the platform reports. It allows the operator to define the plant's dispatch model and configure the optimization algorithm, accessible from anywhere in the plant without needing to install applications or perform any configuration on the user's computer. Furthermore, this web application provides access to the result of the optimization algorithm, a panel of current real-time states of the GUs, the hydrological data collected by the ANA service, maintenance information obtained from the SAU, and configurations of the GU status monitoring module.

4. Results and Discussion

The architecture successfully collects data from all desired systems in both the OT and IT networks of the plant. The main differential of the architecture is the ability to integrate data from different sources so that the end user can access the information without the need for manipulation or execution of complex configuration and export steps. The choice of information of interest is made by the web application, which offers an intuitive method of exporting personalized data, which allows plant employees to obtain insight when it is needed. This export module is constantly being used to help decision-making in the plant.

Using the data obtained and processed by the developed architecture as input, the "operational status identification and monitoring" module presents real-time information about the status of the GUs on a panel in the operating room, enabling operators to make important decisions about which UGs can be used in the generation, which are under maintenance and which have some restriction, all based on accurate information, while without the application, the identification was made manually and constantly was delayed to be updated into the systems.

Furthermore, the integration allowed the development and enhancement of the methodology for scheduling the generation (DESSEM) for the days ahead. The engineers responsible for the scheduling had to look for data in at least three different systems: operational data from the SCADA system, hydrological predictions from spreadsheets built by the hydrology department, and maintenance schedule from SAU; compile them and only then plan the scheduling. The module developed for the DESSEM currently is in the testing and validation phase, and it automatically compiles the data and generates the schedule; the engineers only need to validate the scheduling and then upload it to ONS

The integration also allowed the development of an optimization algorithm based on Markov Decision Processes Techniques to determine in real-time the best dispatch of generating units considering the conditions of the plant. The algorithm mainly focuses on the hydraulic losses caused by the accumulation of material in the water intake railings. This module is also in the testing and validation phase in the plant. Nevertheless, it will facilitate the unit commitment process for operators while ensuring the best use of available water resources.

5. Conclusion

The developed architecture successfully integrates and concentrates information from different plant sources, contributing to the IT/OT tools convergence, enabling real-time decision-making based on greater operational intelligence, and thus allowing the Jirau HPP operation optimization.

All the modules developed to collect, analyze and provide data from and to different systems are in active use on the plant. Moreover, the successful integration of Jirau HPP systems allowed the development of two modules to optimize the plant operation directly. One is focused on pre-operation activities, mostly the generation scheduling for the days ahead. In contrast, the other focus is on the real-time dispatch of generating units according to the actual hydrological scenario. These modules are currently in the testing phase on the plant but are already showing positive results in the operation.

Finally, the modular architecture ensures the ability that any eventual new functionalities can be incorporated in the future, further expanding the tool's application capacity.

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References

[1] Scholten, Bianca. "*The road to integration: A guide to applying the ISA-95 standard in manufacturing*". Isa, 2007.
[2] Lipnicki, Piotr, et al. *"Future of IoTSP–IT and OT integration."* in *2018 IEEE 6th International Conference on Future Internet of Things and Cloud (FiCloud)*. IEEE, 2018.
[3] Garimella, Phani Kumar. *"IT-OT integration challenges in utilities."* in *2018 IEEE 3rd International Conference on Computing, Communication and Security (ICCCS)*. IEEE, 2018.
[4] Hagner, Steven. *"Optimizing transmission asset health with IT/OT integration."* in *2016 Saudi Arabia Smart Grid (SASG)*. IEEE, 2016.
[5] Gadré, Isabelle, and Vackerberg, Jens-Martin. "*Predicting the rate of adoption of IT/OT integration in the Swedish electricity grid system*". Master thesis. Sweden, 2016.
[6] Jirau Energia, The Structure of Jirau Hydroelectric Power Plant, <https://www.jirauenergia.com.br/en/conheca-a-uhe>
[7] AVEVA OSIsoft, PI System – Connecting data, operations & people | OSIsoft|, <https://www.osisoft.com/pi-system>