Design of a State-of-the-art Collaborative Process Automatic System for the Harbour Area Treatment Scheme Stage 2A

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Abstract
This paper will provide an overview of the design of the Sewage Treatment Process Control System (STPCS) for the Harbour Area Treatment Scheme Stage 2A (HATS 2A). The STPCS will adopt the concept of Collaborative Process Automatic System (CPAS). It will also explore the issues and challenges identified during the design process of CPAS, combining reflections with concrete experience for knowledge sharing.

Keywords
Collaborative Process Automatic System, process automation, process control, sewage treatment

INTRODUCTION

Summary
Hong Kong’s Victoria Harbour is considered as one of its most important natural assets, second only to its people. It is also one of the best sheltered and the busiest ports in the world (Smith, 2010). To preserve this important asset from pollution caused by the discharge of up to 2.44 million m$^3$ of sewage every day, enough to fill up 1,000 standard-size Olympic swimming pools, the Government of the Hong Kong Special Administrative Region initiated the Harbour Area Treatment Scheme (HATS) (DSD, 2010), which is an integrated sewage treatment system that collects and treats all sewage from the harbour areas in an efficient, effective and environmentally sustainable manner (see Figure 1). The first stage of the project, HATS Stage 1, collecting and treating 75% of this sewage and designed to serve a population of 3.5 million people, was commissioned in December 2001.

The next stage of the project, HATS Stage 2A, which now is in construction phase, will collect and treat the remaining 25%. Together with HATS Stage 1, it will be able to serve an ultimate population of 6 million. A new process automation system will be set up for HATS Stage 2A. The main challenge is the need to provide a system that will seamlessly integrate the existing process and automation system, which has been in service since 2001, and the new process automation system together with the existing and new infrastructure for operation efficiency. The integrated system will coordinate the overall sewage collection on both sides of the harbour and the centralized sewage treatment processes at Stonecutters Island Sewage Treatment Works, a no easy task given the size of the catchment area. Moreover, functional enhancements will be incorporated
into both process automation systems, which include an Expert System for process simulation and decision support. It will adopt the concepts of Collaborative Process Automation System (CPAS), the evolved version of Distributed Control System (ARC, 2010).

Figure 1 Harbour Area Treatment Scheme (HATS)

DESIGN OF SEWAGE TREATMENT PROCESS CONTROL SYSTEM

Scope of the New Sewage Treatment Process Control System
A new Sewage Treatment Process Control System (STPCS) will be set up to control and monitor the operation of both HATS Stage 1 and Stage 2A. The main scope of work for the new STPCS is as follows:-

a) To upgrade the existing process automation system for HATS Stage 1, which collects sewage from seven preliminary treatment plants located in the Kowloon peninsula and the eastern part of Hong Kong Island and delivers it through a network of 23.6 km deep tunnels to Stonecutters Island Sewage Treatment Works (SCISTW) for chemically enhanced primary treatment and subsequent discharge through a submarine outfall to western waters (see solid line in Figure 1);

b) To install a new process automation system for HATS Stage 2A, which collects sewage from eight preliminary treatment plants located in the northern and southern sides of Hong Kong Island and delivers it through a network of 21 km deep tunnels to Stonecutters Island Sewage Treatment Works (SCISTW) for treatment (see dotted line in Figure 1); and

c) To integrate the two process automation systems into one integrated STPCS.
Considerations of HATS Stage 1 DCDAS Upgrade

The existing process automation system for HATS Stage 1 is a traditional Distributed Control System called Distributed Control and Data Acquisition System (DCDAS) having an I/O count of about 30,000. It has been put into service since 2001. After over a decade of use, it is becoming increasingly difficult to maintain because spare parts and manufacturer support are no longer available on the market. With some components exceeding their nominal serviceable life spans, the possibility of an impending system failure cannot be dismissed without considerable maintenance effort. Moreover, the limitations of this legacy system prevent users from taking advantage of the new generation of information and automation technologies that are available, such as open networks, expert systems, etc. Therefore, it was decided to upgrade it.

In choosing the approach to DCDAS upgrade, it was decided that simply migrating it or upgrading it to a system that will do what it is doing now would not be enough. That would essentially put the user back to square one, contravening the concept of continual improvement. The upgraded DCDAS should have extra functionalities allowing the use of the new generation of information technology and providing a path to performance enhancement. However, at the same time, there is a need to preserve parts of the legacy system, such as the automation programs now running the plants that have seen numerous optimizations and accumulated years of user experience and knowledge.

As recommended by ARC Advisory Group (formerly called Automation Research Corporation), the system upgrade should be viewed in the same context as a new system installation. In addition, the following issues were taken into consideration:

- Operation of HATS Stage 1 should be maintained non-stop and should not be disrupted during system upgrade;
- Some existing assets, such as the control programs, should be preserved or otherwise converted to the form suitable for the upgraded system by efficient and reliable means;
- Some hardware assets that add no value should be removed;
- Level of control functionality should be equal to or greater than the DCDAS; and
- Advanced applications and the new generation of information technology should be accommodated.

Considerations of HATS Stage 2A Process Automation System

The new process automation system of HATS Stage 2A will be a control and automation system having an I/O count of about 30,000, similar in size to that of DCDAS. Besides those considerations of a new process automation system, the new system must be able to work with the upgraded DCDAS in a seamless manner to form an integrated control system STPCS.

It is difficult enough for two systems of different brands and generations (one procured in the 1990s and the other will be procured in 2010s) to form an integrated system, and it is still harder if the integrated system consists of four to five systems of different brands and generations to work together. This is just the case with the STPCS. Owing to procurement policies and tendering strategies, the procurement of the STPCS resides in different contracts. The result is that the STPCS will be composed of four different versions (different brands or generations) of process automation systems. In the past, the integration could be solved with custom programming, which is not an option in this case because it is both expensive and time-consuming. Therefore, the concept of CPAS was used to unify these diverse systems in order to achieve true integration and operational excellence.
The most important element of a CPAS is its Common Object Model infrastructure, which allows the deep integration of process automation systems from different manufacturers and different technology generations, fieldbus devices, electrical components and higher level operations with enterprise resource planning systems or expert systems. All relevant information is inherently available at all workplaces.

**Adoption and Modification of CPAS Concepts**

Although CPAS, from the functional point of view, should consist of only the automation system and the business system, it is nevertheless decided to preserve the four layers of hierarchical control of a Distributed Control System for the sake of consistency, deterministic operation, and clarity, in view of the fact that the STPCS is a mission-critical automation system. This structure is provided for Process Control applications by the ISA 88 Reference Model (although ISA 88 is for batch rather than continuous process control) (ISA, 2010), and for Operations Management applications by the ISA 95 Reference Model (ISA, 2007). However, for a major proportion of the STPCS, it still satisfies the CPAS principle of “a common infrastructure, functionally transparent, logically concise and standards based” and “no artificial barriers to information” by adopting Ethernet TCP-IP in the “Common Information Infrastructure” of the dual ring as illustrated in Figure 2 on the architecture of the STPCS.

Moreover, in the STPCS, the programming languages are required to comply with IEC 61131-3, which organizes and prescribes the use of the five most commonly used process control languages. To reduce future maintenance effort further, only “functional blocks” will be used in the STPCS. Re-use of functional blocks are also required. Together with the two Reference Models, it contributes to a CPAS principle of “flawless execution”.

Lastly, the concept of Global Data Access (GDA) is adopted for the integration of the four process automation systems. GDA requires every element of the STPCS to be addressable as an object with a unique name. This has the benefit of accessing data directly from the source and not requiring...
intermediate data stores, hence achieve “common data model” and “single version of truth”. The elimination of intermediate data storage and processing enables all data exchanges to be in parallel and achieve “software redundancy”. With hardware redundancy being built into the design of the STPCS, its availability can be improved further.

**Architecture of the STPCS for HATS Stage 1 and Stage 2A**

The architecture of STPCS is divided into four levels (see Figure 2), namely Field Device Level, Control Device Level, Operational Device Level, and Management Device Level according to the ISA-95 series of standards (ISA, 2007).

The **Field Device Level (FDL)** is realised by field devices connected to input/output modules through conventional I/Os and field buses such as Profibus DP and MODBUS. The use of Foundation Field bus, which is considered to be more advanced in technology, was considered during the design stage but was not adopted because of the limited range of field devices supported as compared with Profibus DP and MODBUS.

The **Control Device Level (CDL)** is realised by connecting controllers, I/O cards and other electronic cards through networking cables or fiber links in proprietary control protocol such as Profibus DP, Foundation Fieldbus HSE, DeviceNet, ControlNet, Ethernet TCP/IP, etc. This is the 2nd level in the hierarchy that mainly focuses on the connections between the controllers and the I/O modules.

The **Operational Device Level (ODL)** is realised by the network switches, operator terminals, engineering workstations, gateway servers, historian data servers, printers and peripherals which was connected to the control devices through dual optical fiber rings through standardized networking protocol. This is the 3rd level of hierarchy that connects different controllers and servers.

The **Management Device Level (MDL)** is realised by the computerized maintenance management data servers, historian servers, expert systems, and other information systems connected to the ODL through networking cables in Ethernet TCP/IP 1000BASE-T network conforming to IEEE802.3. This is the highest level of the system that focuses on the connections of different application servers together to form a total management solution for the daily operations and decision making and reporting. In fact, this level enables integration of the new generation information technology system into the STPCS. It allows the operators to monitor the whole treatment process with report on exception features, and to highlight specific operation mode for ad-hoc operational requirement such as unexpected rainstorm in some regions.

**IMPORTANT ELEMENTS OF STPCS**

The STPCS has the following important elements:

**Scalability and Flexibility**

To minimise system life-cycle costs and enable ad-hoc expansion, the STPCS is designed to be of modular type and field expandable. Moreover, with the adoption of an “Open System”, GDA, and standardized programming languages, the STPCS is able to be integrated with process automation systems from any manufacturers with relative ease.
Availability and Fault Tolerance
The STPCS is designed to have system availability not less than 99.95%. The system will maintain its normal operation even during any single point of failure within the system. This is achieved through control system hardware redundancy and “software redundancy” realized by GDA.

Usability
The STPCS will present to operators a single view of the current performance, which means “a single version of truth”, a principle of CPAS. Moreover, some prescribed procedures will be automated. Furthermore, the Decision Support System provided with the STPCS can relate current operation or possible changes of operation to a risk scenario for reference by operators – an element of knowledge management. With these features, operator training time can be reduced and operability improved.

Maintainability
The maintainability of the system can be looked at from the hardware and the software points of view. From the hardware point of view, increased maintainability is achieved primarily by modular approach to system components and the availability of diagnostic tools, from basic indicators such as LEDs on boards to Expert System. On the software side, maintainability is enhanced by the late binding technology (dynamic linking) and publish/subscribe technology of CPAS. These technologies enable objects to be accessed at run time and therefore can save much of the configuration efforts. Moreover, source location will be made independent, making it much easier to move I/O components.

Alarm and Event Management
Normal operation ranges of control parameters for relevant operating parameters and set points (for example: inflow, shaft level, number of pumps running, pH, turbidity level etc.) will be monitored and/or checked against the normal ranges when required by the operators. Alarm messages shall be activated to alert the operators to any abnormal operation conditions. All alarm information will include equipment types and attributes. Equipment types refers as pump, compressor, blower, on-off valve, control valve, diffuser, mixer etc. and attributes refers for a pump shall include, status, alarms, hours run, flow, pressure, speed etc.

All these informative details will be stored in the Knowledge Base of an Expert System. Possible causes of alarms and sequence failures recommended by the Expert System can assist the operator in fault diagnosis and identify the root cause of the problem. The expert knowledge from the results of various simulation models shall be input in the Knowledge Base and be accessed by the operators for daily reference.

Integration
Operations, engineering, and information management as the typical tasks will all be available within one integrated environment. A unique tag code naming of the equipment will be re-designed to unify the operations for addressing the single item within the whole system (Garcia and Gelle, 2006).

All equipment of the new STPCS will be integrated to perform as a single system according to the Common Information Infrastructure through the use of common interface equipment, interface protocols and network hardware.

The STPCS will support the use of devices from multiple manufacturers on the same field bus and will support the ability for a field device from a given manufacturer to be replaced by one of the
same type (e.g. temperature measurement instrument) from a different manufacturer without loss of functionality. In addition to the fieldbus connections, the configuration software shall all support these features. Therefore, the Interoperability and Interchangeability of the system will be greatly improved.

**KEY PROJECT CHALLENGES**

The key project challenges come from two main sides: technical and human.

On the technical side, the biggest challenge is to maintain normal operation of HATS Stage 1 during DCDAS upgrade. Any major disruption to DCDAS may cause sewage bypass to the sea, causing environmental pollution and bad publicity. The approach to DCDAS upgrade should be well thought-out and components of the upgraded process automation system thoroughly tested before change-over. Contingency plans to respond to potential failures should be formulated and drills carried out.

Another technical challenge concerns the adoption of the ISA 88 Reference Model, which is designed for batch process control rather than continuous process control, such as this case. The model has to be modified according to the knowledge and experience of the designer with due consideration to the plants and their quirks for its adoption. The use of sequence logic allows procedures to be automated but it has to be done in an ad-hoc framework using custom programming methodologies, making future upgrade cumbersome and expensive. Considerable efforts have been expended to compile documentation to make future upgrade easier.

The integration of different versions of process automation systems into a single STPCS poses a challenge of its own in terms of project management. Although a CPAS should allow different systems to integrate seamlessly, implementation is being carried out by a few contractors and interface problems inevitably arise between them that require discussions and negotiations to resolve.

Human issue is another major factor determining whether the project is successful or not. Front line operators can be conservative in revamping the existing systems to incorporate the latest automation and control solutions. They may also be reluctant to learn new working methods and new technologies in their working environment. This could have either prohibited or delayed the implementation programme of the STPCS. The way to resolve this potential problem was to get early involvement with the frontline operators, seek inputs from them during the design stage, include their comments in the system design, and let them be part of the project team. The overall automation strategy should be a product of the numerous discussions between designers, contractors, and users - allowing operators to do what they do best and system to do what it does best.

**CONCLUSION**

In the future, there is the demand of ever improving cost-effectiveness in sewage treatment – dwindling resources and more stringent requirements in terms of energy efficiency and effluent standards. Moreover, experienced operators can retire or leave resulting in loss of experience and knowledge. The vision of CPAS provides an encouraging solution to these enduring problems by allowing access to any information from anywhere to anywhere at any time for any valid purpose, “the five anys”, which is the Holy Grail of a modern process automation and information system.
The overall performance of future plant can be greatly improved through the empowerment of the operator (Woll et al., 2002).

REFERENCES


