Migration of Industrial Process Control Systems into Service Oriented Architecture

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Abstract—The procedure of migrating SCADA and DCS functionality of the ISA-95 process automation architecture to a Service based automation architecture is discussed. Challenges in such migration are discussed and defined. From here the necessary migration technology and procedures are proposed. The critical migration technology is based on the mediator concept. The migration procedure is based on a functionality perspective and comprises four steps: initiation, configuration, data processing and control execution. Its argued that these steps are necessary for the successful migration of DCS and SCADA functionality in to the automation cloud.

I. INTRODUCTION

There is a demand in the process industry to modernize the process control equipment as aging process control systems become maintenance intensive; in addition older systems certainly lack technical capabilities and features of newer ones. Service Oriented Architecture (SOA) is seen as a promising candidate to support cross-layer integration to make distributed systems more interoperable. Such technology shift has been in progress at the enterprise system level for many years. The technology has been pioneered by IBM and others, important contributions has been made by many, some examples can be found in [1] e.g. This statement is the result of certain European collaborative projects, such as SIRENA [2], SODA [3], SOCRADES [4]–[6], that demonstrated the feasibility of embedding Web Services at the device level and integrating these devices with MES and ERP systems at upper levels of an enterprise architecture [5]. Other projects which indicate the same development of industrial control systems include the European Initiatives PLANTCockpit, <http://www.plantcockpit.eu/>; KAP, <http://www.kapproject.eu/>; ActionPlanT, <http://www.actionplant-project.eu/the> European Embedded Systems Platform Advanced Research & Technology for EMbedded Intelligence and Systems - ARTEMIS, <http://www.artemis.eu/>.

Those projects listed here were mainly addressing factory automation, whereas the IMC-AESOP [7]–[9] project considers applying the SOA paradigm to approach the next generation of SCADA/DCS systems with major focus to the process industry and industrial process control systems. The SoA paradigm applied to Control and Automation provides with technologies, methods and tools that can enhance interoperability by decoupling functionality and their implementation.

Fig. 1. ISA95 architecture of automation system, functional hierarchy according to (IEC 62264-3) [11], [12]

As a consequence, the transparency of the entire infrastructure, including systems development tools and devices, is increased.

Several provider of todays enterprise systems, Level 4 in the ISA-95 architecture please refer to Fig. 1, already support service-driven interaction e.g. via Web Services. Service Oriented Architecture is an approach used at this level. Services are also used for integration between Level 3 and Level 4 systems, available on the market. OPC UA [10] is a technology spreading-up to be used. PLCopen in close cooperation with OPC Foundation, defined a OPC UA Information Model for IEC 61131-3. A mapping of the IEC 61131-3 software model to the OPC UA information model, leading to a standard way how OPC UA server-based controllers expose data structures and function blocks to OPC UA clients like HMIs was defined [2]. OPC UA relies on Web Service based communication. Last year, a working group was established focussing on the definition of communication mechanisms via OPC UA for MES integration of Level 2 systems as well as the definition of the semantics for MES integration. Those activities can be seen as attempts to move towards the use of common technologies across different levels of production systems.

Legacy systems typically have proprietary protocols and interfaces resulting in vendor lock-ins and possibly site specific solutions; however with SOA these systems can be wrapped and integrated in a modern infrastructure. By abstracting

from the actual underlying hardware and communication-driven interaction and focusing on the information available via services, the complete system is managed and controlled by service-driven interactions. Services can be dynamically discovered, combined and integrated in mash-up applications. By accessing the isolated information and making the relevant correlations, business services could evolve; acquire not only a detailed view of the interworking of their processes but also take real-time feedback from the real physical-domain services and flexibly interact with them.

The legacy systems are typically implemented following the 5-level model as defined within the ISA 95 / IEC 62264 standard (<http://www.isa-95.com>). Operations, defined by that standard, are inherent to established production management systems [11]. In this context, concepts for integrating legacy systems, specifically on lower levels, into Service Oriented Architecture based systems can be seen as business enablers to take the customer from where she/he is today [9] into the future.

The novelty of migrating from a legacy process control system into a SOA, is to in a structured way, gradually upgrade highly integrated and vendor-locked standards into a more open structure while maintaining the functionality. This paper focuses on the process of migrating industrial process control systems into a SOA-based architecture. The challenges of step-wise migration of a highly integrated vendor-locked DCS (Distributed Control System) and/or SCADA (Super-visionary Control and Data Acquisition) are discussed. The approach taken addressing functionality. From here the necessary migration technology and procedures are proposed. The critical migration technology proposed is based on the mediator concept. The migration procedure proposed is based on a functionality perspective and comprises four steps: initiation, configuration, data processing and control execution. Its argued that these steps are necessary for the successful migration of DCS and SCADA functionality into a service-based automation cloud.

II. CHALLENGES IN MIGRATING INDUSTRIAL PROCESS CONTROL SYSTEMS

Today's control systems, as used in process or manufacturing automation, are typically structured in an hierarchical manner as illustrated in Fig. 1.

IEC 62264 (or originally ISA 95) [11] is the international standard for the integration of enterprise and control systems, developed to provide a model that end users, integrators and vendors can use when integrating new applications in the enterprise. The model helps to define boundaries between the different levels of a typical industrial enterprise. ISA 95/IEC 62264 define five levels. For each of these five levels certain problems and challenges becomes eminent when considering their implementation using a SOA based approach.

Whereas Level 0 is dedicated to the process to be controlled itself, Level 1 connects the control systems to the process by sensors and actuators. Through the sensors the control system can receive information about the process and then regulating the process through the actuators. Sensors convert temperature,

pressure, speed, position etc. into either digital or analogue signals. The opposite is done by actuators. Including not only valves but also motors and motor equipment such as frequency converters in actuators, it can be said that the level of installed intelligence varies very much. Legacy implementations use a scan based approach reading and writing data from/to sensors/actuators. Which differs fundamentally to the event based nature of a SOA approach [8], [13]. Migration on Level 1 has to some extent been described by Delsing et. al. [14] with focus on transition from scan-based to SOA event based communication when it comes to analogue signals.

At Level 3, operational management of the production is done, where Manufacturing Execution Systems (MES) provide multiple information and production management capabilities. In the context of control hierarchy, however, its main function is the plant-wide production planning and scheduling. In a continuous process plant, the results of scheduling are used as production targets for individual shifts, and consequently, translated by engineers and operators into individual set points and limits. Level 3 integrates information about production and plant economics and provides detailed overview about the plant performance. If the production is straight forward with few articles and small production site, a dedicated Level 3 system might not bring added value. Some typical MES/MIS functionality is instead put in Level 2 and/or in the ERP-system (Level 4). At Level 4, typically Enterprise Resource Planning Systems (ERP) are installed for strategic planning of the overall plant operation according to business targets. Migration into SOA at Level 3 and 4 does not differ significantly for factory automation and process control systems [6]

At Level 2 there are some non-resolved challenges of migration when it comes to the process industry. Distributed monitoring and control enables plant supervisory control. The distributed control system (DCS) of a large process plant is usually highly integrated compared with a SCADA solution which is standard in factory automation. The SCADA is a supervisory system for HMI and data acquisition and the system communicates through open standard protocols with subordinated PLCs. The PLCs in the SCADA solution are autonomous compared to their counterpart, which sometimes are referred to as controllers, in the DCS. In this paper the process control system is defined as a DCS including HMI workstations, controllers, engineering station and servers all linked by a network infrastructure. A DCS is truly "distributed," with various tasks being carried out in widely dispersed devices. Migration of Level 2 functionality in the form of a DCS exhibits challenges when it comes to co-habitation between legacy and SOA as well as the migration of the control execution [8], [13]. In this paper the DCS is exemplified by a server/client based system as depicted in Fig. 2, which is a common topology.

When migrating the DCS into SOA there are certain requirements based on expectations from business, technical and personnel perspectives:

- The new architecture and the migration strategy must assure the same level of reliability and availability as the

Fig. 2. Legacy system architecture

legacy system.

- The migration procedure must not induce any increased risk for staff, equipment or process reliability and availability.
- After the migration the plant must still provide the same or a better process, extended service life of plant (process equipment e.g. pumps, vessels, valves), adequate information and alarms depending on department and personnel skill and improved vertical (cross-layer) communication with more information available at plant wide level.
- Dynamic changes and reorganization is expected to be supported, on a continuously running system.
- To handle to co-habitation between the legacy system and the SOA during the migration phase, the SOA solution must support wrapping of legacy sub systems.
- Fieldbus systems, like Profibus PA today already define standardized ways of error indication by devices [15]. With the intelligence built into SOA devices troubleshooting is expected to be improved.

In order to migrate a highly integrated DCS the following challenges should be addressed:

- **Preserve functional integration:** There are advantages with a highly integrated DCS, which give a tight link between the HMI and control execution. Thus design engineering, commissioning and operation can be pursued in a significantly more uniform way. For instance, the HMI and control execution can be configured by the same tools, which facilitates conformity. These advantages must be maintained even though the integration is broken down and substituted by open standards.
- **Grouping of devices:** Within a given system, it must be determined which devices should be migrated to SOA as devices and which devices should be grouped together and the group migrated to SOA. As example

a subsystem using feedback and regulation might require legacy interfaces because of real-time demands, therefore such group of devices should be given an SOA interface for the group using a Mediator and not at device level. This part of the system may be handled as "black-box"

- **Preserve real-time control:** The real time control execution, which in the legacy system is secured in the controllers, must be preserved.

III. MIGRATION PROCEDURE

Interfacing and integrating legacy and SOA components of a DCS/SCADA system will require some, for the purpose developed and/or adapted, technology. Such integration may be based on some kind of integration component like Gateway or Mediator. Such Gateway or Mediator have the task to bridge the communication from major standardized protocols used close to field applications today: HART communication supported by HCF, Profibus PA in combination with Profibus DP, Foundation Fieldbus, etc. These protocols follow specific characteristics. Some commonalities can be monitored like concepts for device descriptions or integration mechanisms into DCS (e.g. EDD, FDT, FDI). The same bridging task exist regarding communication to higher level, technologies related to Enterprise Application Integration (EAI) or Enterprise Service Bus (ESB) or OPC (OPC DA, OPC UA) are used having their own characteristics and configuration rules.

The use of Gateways or Mediators is a well proven concept for integrating/connecting and migrating devices, attached to different networks. It is used to transform protocols as well as syntax of data. Semantic integration is hard to achieve. Nevertheless it is possible to do transformation between data centric approaches, as typically followed by fieldbus concepts, and service oriented, event centric, approaches.

The Mediator [16] concept used here is built on the basis of the Gateway concept by adding additional functionality.

Originally meant to aggregate various data sources (e.g. databases, log files, etc.), the Mediators components evolved with the advent of Enterprise Service Buses (ESBs) [17]. Now a Mediator is used to aggregate various non WS-enabled devices or even services in SOAs. Using Mediators instead of a Gateways, provides the advantage of introducing some semantics or to do pre-processing of data coming from legacy networks, e.g. representing a package unit. Due to the diversity of data, or different aspects of interest, that different applications request different types (e.g. quality, quantity and granularity) of data, interface devices will normally be built as a combination of Gateway and Mediator. As it may also be applicable to integrate service oriented sections (e.g. retrofit of a plant section or replacement of a package unit) into existing systems, this Gateway and Mediator concept can be extended to represent services into data centric systems (today's legacy systems). Mediator as well as Gateway concepts, both are powerful means for integrating single legacy devices or legacy systems encapsulating isolated functionalities. Whereas the operational phase of a system will benefit from the functionalities described above from the beginning of the migration process, engineering will be characterized by a stepwise approach, starting with defining services representing the legacy device or system, followed by separate engineering steps for the legacy part and the SOA based part using those services defined. Specific configuration effort for the Mediator or Gateway itself is needed. It is advisable, that commissioning will also be done in a multiple step approach, starting at the isolated components followed by their integration into the overall system.

Considering the layout of a server/client-based SCADA/DCS a stepwise migration through four major steps is proposed. The four major steps may contain sub-steps and may be spread out over a long period of time but each major step should be completed before the following step is initiated. The four major steps suggested are:

- Initiation
- Configuration
- Data processing
- Control execution

During the whole migration the system will require one or more mediators to allow communication between the SOA components and the parts of the legacy system that not yet has been migrated. The propagation of the mediator and the growth of the SOA cloud are exemplary applied to the migration of the legacy SCADA/DCS presented in Fig. 2. Making emphasis in the DCS-part, the set of Figs 3 to 6 shows the different results reached throughout the whole migration process.

A. Step 1: Initiation

The initial SOA "cloud" needs some of the basic services presented in [18] in order to support basic communication and management of the cloud. Once the basic architecture is constructed the first peripheral subsystems can be migrated and new components can be integrated in SOA. In migration of subsystems, as well as integration of new components, some

consideration must be made of the limitations of the mediator and its communication paths.

The systems migrated in this step include sub system which are not directly part of the highly integrated DCS:

- Low level black box
- High level systems for business planning and logistics such as maintenance systems

Migration is limited to the operational phase of the systems integrated. Within that step, engineering is out of the scope of migration. An appropriate engineering approach, dedicated to this migration step, is doing multi-step configuration:

- Configuration of every legacy system including the legacy interface within the mediator
- Configuring the SOA system
- Configuring the model mapping within the mediator

Exploiting machine readable legacy configuration information would be helpful for every step. Today, configuration information is available through different technologies e.g. GSD, DD, paper documentation. This type of information is mostly available for single devices. Engineering stations take these information as input and generate system configuration information in proprietary formats.

B. Step 2: Configuration

This is the first step where components that are heavily integrated in the DCS are migrated. The purpose of this step is to migrate parts of the DCS that do not require very short response times or the regular transport of large amounts of data. Please refer to Fig. 4. The majority of functions that qualify for this migration step are in some way concerned with configuration of different parts of the DCS. The point of origin for most, if not all, configuration is the Engineering Stations (ES) which is used for engineering and configuration of most parts of the DCS.

As the ES is migrated to SOA, this constitutes a major increase in the number of services the Mediator needs to supply to the SOA cloud as it must in addition to the operational data migrated in the first step represent configuration aspects of all legacy systems and devices not yet migrated, and allow configuration of all systems and devices. This means that configuration of low-level devices and control is done on the ES in a SOA environment using configuration services provided by the mediator, the configuration is then compiled by the mediator into their respective legacy formats and downloaded into the legacy controllers. Configuration of HMI, Faceplates and associated systems is similarly done in SOA and converted by the mediator to a format that can be downloaded into the legacy Aspect servers and other legacy systems. The configuration of legacy devices from SOA might also require that the mediator is able to extract legacy designs and configurations that may be stored in aspect servers or controllers so that old designs can be reused and modified by the SOA Engineering stations.

As legacy systems usually do not provide sufficient meta-data, sufficient configuration information can not necessarily

Fig. 3. DCS after the first step of migration

Fig. 4. DCS after the second step of migration

be extracted by a Mediator from the installation (legacy systems). Today, configuration information is available through different technologies (GSD, DD, paper documentation, .). This type of information is mostly available for single devices. Engineering stations take these information as input and generate system configuration information in proprietary formats not necessarily interpretable by other tools.

Consequently, for overall engineering a SOA engineering station should be able to import relevant configuration information of different legacy systems in addition to the limited capabilities provided by the Mediator itself. If such a tool would be available, one could design a mediator acting as configuration station for different legacy systems (compile configuration information into legacy formats) while receiving basic configuration information from the SOA engineering station.

This approach may be combined with doing multi-step configuration described in the former step.

C. Step 3: Data processing

In this third step, the migration includes all components and/or subsystems that do not require short response time

(millisecond range) not currently achievable by the SOA technology. Please refer to Fig. 5. This includes Operator Clients (OP) and Operator Overview Clients (EOW) as well as Aspect Servers (AS) and Information Management Servers (IM). As all points of user interaction with the system is now moved to SOA this means that the legacy Domain Servers (DS) are redundant. However, as user management and security needs to be available in SOA from the first step of the migration, there is probably no need for the Domain Servers in the SOA cloud, although the functionality can be considered to be migrated.

The migration of the Operator Clients and the Aspect and Information Management servers mean that the role of the mediator is once again fundamentally changed. In Step 3 of the migration there is less of a need for a flexible mediator that can communicate with a lot of different legacy components, the new requirements are more concerned with a need to present large amounts of data available from legacy controllers to the migrated Operator clients and other data processors and consumers. This activity is closely related to the purpose of the Connectivity Servers (CS) and it is suggested that the mediator in Step 3 is implemented as a new interface in the Connectivity

Fig. 5. DCS after the third step of migration

Servers.

D. Step 4: Control execution

In the fourth and final step of migration the time has come to migrate the functionality traditionally provided by controllers. Please refer to Fig. 6. As control execution in the legacy system can be grouped together with several control functions in one controller, or in some cases spread out with different parts of a control function executed by more than one controller, it is of utmost importance that control execution is migrated function by function rather than controller by controller.

Depending on the performance requirements of each control function there may be a need for different strategies for different functions. In the cases where SOA compliant hardware is available for all functions an Active Migration may be suitable where a detailed schedule can be made over the migration of all functions, enabling a controlled migration towards a set deadline. In other cases it may be suitable to allow legacy controllers to fade out as functions are migrated in the course of normal maintenance and lifecycle management of the plant. The fade out option means that Step 4 of the migration may take a very long time but it may save costs as legacy devices are used for their full lifetime, while most benefits of SOA are already available.

IV. CONCLUSION

Following and extending the initial migration concepts introduced in [14], the novelty of migrating from a ISA'95-

based legacy process control system into a SOA is to proceed in a structured way, gradually upgrading highly integrated and vendor-locked standards into a more open structure while maintaining the functionality. A procedure migrating the functionality of a DCS/SCADA to a cloud SOA based implementation is proposed. The procedure comprises 4 distinct steps and make use of mediator technology. These 4 steps are designed to maintaining the feeling of conformity between HMI and control execution and that the target system must exhibit full transparency and support open standards. It is important that the initiation in Step 1 consider these issues in order to enhance the plug-and-play feature of a SOA system even in an industrial process control system. The parts of the DCS/SCADA where operations and engineering are handled will in a structured way be migrated in Step 2 and Step 3. When it comes to the control execution, its migration approach is decided upon based on functionality and real-time requirements. If utilizing the fade out approach the most critical control loops and control logics may stay with their legacy set-up, in which operational, engineering and maintenance staff are confident. When these critical functions finally are upgraded they will be completely SOA compatible, whereas the real-time execution is run on device level.

Using this step wise approach, utilizing SOA and mediator technology, it is argued that the SOA approach will: preserve functional integration, support grouping of devices, preserve real-time control and successful addressing of safety loops. Making emphasis in the DCS-part of an exemplary legacy

Fig. 6. DCS after the forth step of migration

SCADA/DCS, the authors applied the approach and present the results reached throughout the whole migration process.

Within the scope of IMC-AESOP project [7] the next step aims at evaluating the results of applying the migration procedure in dedicated industrial use-cases. Having in mind that one of the major results of the migration is the transformation of the ISA-95 architecture into a Automation Service Cloud. Future work will be oriented to extend the migration process and procedures to comprise the full ISA-95 architecture including security issues.

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