BEST APPROACH TO UPGRADING A DISTRIBUTED CONTROL SYSTEM

CASE STUDY: KIIRA POWER STATION

A Dissertation

Presented to

The Engineering Institute of Technology

by

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In Partial Fulfilment

of the Requirements for the Degree

Master of Engineering in

Industrial Automation

May 2018

ACKNOWLEDGEMENTS

My sincere gratitude goes to my supervisor, Dr. Yuanyuan Fan, who has guided me through this journey. I would like to also appreciate the Engineering Institute of technology for granting me the opportunity to tap from their vast wealth of knowledge, both from the lecturers and the course material availed. Special thanks go to my employer, Eskom Uganda Limited, that has fully sponsored me for this course. I would also like to appreciate my family and friends for the support rendered. Above all, I thank God who has brought me this far and pray that He blesses all those that have journeyed with me.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

KPS	Kiira Power Station
LCC	Lugogo Control Centre
AC410	ADVANT Controller 410
DCS	Distributed Control System
HMI	Human Machine Interface
MW	Mega Watts
MWh	Mega Watt-hour
AC70	ADVANT Controller 70
OEM	Original Equipment Manufacturer
kV	Kilo Volts
TCO	Total cost of ownership
I/O	Input / Output
NPV	Net Profit Value
NV	Net Value
LED	Light Emitting Diode
OS	Operator Station
DC	Direct Current
CPU	Central Processing Unit
MTTF	Mean time to fail
MTBT	Mean time before trip

MTBF	Mean time before failure
AMPL	ABB Master Piece language

ABSTRACT

Distributed control systems are widely used in power generating plants to control, monitor and ensure efficient, reliable and effective power generation, to match the ever-increasing demand for power. Hydro power plants are designed for a minimum life of 50 years, however, their control system last for far less, at approximately 20 years. As such, power plant owners usually neglect the control systems until such a time when the spares are no longer available. Technical support becomes scarce as a result of the original equipment manufacturers having upgraded their products, rendering the older versions obsolete. When the control system reaches its end of life, an upgrade or migration is inevitable.

There are numerous reasons as to why power plants continue running on old Distributed Control System networks. One of the reasons is failure to justify cost of investment for system replacement when the control system is still operational. Even when the upgrade decision has been made, there is difficulty in deciding which strategy to use; rip and replace or phased approach.

In this thesis, an analysis of common factors leading to system obsolescence and its impact are highlighted. A cost benefit analysis is used to justify why an upgrade should be done and this is based on the total cost of ownership as well as the Net Profit Value of the old and new system.

CHAPTER 1: INTRODUCTION

Distributed control systems in industrial processes provide communication between distributed controllers to achieve efficiency and reliability of the process. Power plants, especially hydro power plants have a design life of at least 50 years. Unfortunately, their control systems have a much less life of between 15 to 30 years [1]. As such, the plants begin to experience faults associated with aged controls with no exception to the distributed control systems (DCS). An old or legacy DCS can be defined as one that is difficult or impossible to modify and/or evolve to latest state-of-the-art-technology in terms of software and hardware. As the DCS age, they experience several defects and shortcomings such as [2] [3]:

- Costly, time-consuming fault tracing and software maintenance due to missing documents as well as lack of knowledge of the system software and internal functionality.
- The obsolete software and hardware on which the systems run is costly to maintain and usually very slow.
- Expansion of old DCS is either impossible or very expensive
- Lack of clean interfaces makes integration difficult

As technology evolves and the need for power grows, power plants will require migrating legacy DCS to newer environments allowing for easy maintenance and adaptation to demand. These have to be achieved while maintaining functionality of the entire system without doing a complete re-development of the system. This justifies the need to look at how and when to migrate an existing DCS.

1.1 Case study: Kiira Power Station (KPS)

Kiira Power Station is a hydro power plant with a net installed capacity of 200MW derived from five vertical shafts, fixed blade Kaplan turbine machines each generating 40MW at a head of 21m. The first and last units were commissioned in 2000 and 2007 respectively. The power plant uses an ABB distributed control system of the ADVANT family, made of two operator stations-HMIs (which are used to start, regulate, monitor parameters and shut down units), five-unit computers, one station computer, one switch yard computer, of the type AC410 while the one auxiliaries' computer is an AC70. Both AC410 and AC70 were declared obsolete by the OEM in 2016 and 2015 respectively.

The switchyard computer provides a communication interface between the 132kV switchyard in Nalubaale Power Station, KPS generating units and Lugogo Control Centre, which monitors the country's power generation and distribution. The KPS station computer relays signals from various transducers and equipment around KPS to the KPS process computers, significantly boosting plant monitoring and diagnosis in case of a failure. The Station and switchyard computers are non-operational because of hardware breakdown problems that cannot be fixed due to unavailability of spares. ABB's product life cycle management schedule indicates that the ADVANT (AC410) was declared obsolete.

It is thus necessary for the DCS controllers to be replaced with new versions of technology that are still being manufactured, supported, have spares on market. In such a case as KPS, the engineers need to consider many factors when planning the upgrade project, such as, replacing the entire network at once, or doing it in phases. They also need to consider whether to or not maintain the existing OEM.

1.2 Justification

Hydro power plants are designed to last for over 50 years of service. To maintain efficiency and reliability of the plants, many rehabilitations and refurbishments are done over the years. As such, the control systems of such long serving plants also require upgrades and migrations as they soon reach the end of their lifecycle, becoming obsolete [3]. Towards the end of the DCS lifecycle, human resource knowledgeable about the system become scarce due to retirement and product spares and technical support become scarce. As the control system ages, sudden malfunctioning of the system is inevitable, and this usually results into sudden process shutdowns, long downtime due to lack of spares and support accelerated by incompatibility of the current market technology with the old/legacy systems [4].

As technology changes, there is rapid development in the field of process and industrial automation forcing the vendors of DCS to upgrade their systems to accommodate the latest-state-of-the-art technology. With such advancements, production lines for legacy systems are terminated, phasing out and reducing technical and spares support for the legacy system. The vendors then, advise users of the legacy systems to upgrade to the latest systems to prevent the adverse effects of equipment obsolescence and sudden component failure. Factors influencing the decision to replace legacy/obsolete systems have been studied for a while, including [5] that developed a technology obsolescence model that analysed various factor that influence the replacement of obsolete system biased to computers and their software. It is thus important to plan for the power plant control system taking into consideration what strategy to use to maintain and upgrade old/legacy control systems with as minimum interruption to production as possible.

1.3 Thesis objectives

This research aims at analyzing upgrading and migration strategies for legacy/old distributed control systems to the state-of-the-art control systems, minimizing cost, risk and process downtime.

The specific objectives towards addressing the issues around migrating a DCS include:

1) Avail guidelines to establish when a DCS is due for replacement by reviewing common factors that motivate for a DCS upgrade or migration, using KPS hydro power plant as a case study.

2) Analyze strategies that can be followed for existing DCS upgrade: Provide general guidelines and methodologies on how to upgrade a DCS.

These objectives will be achieved by applying a cost benefit analysis for maintaining an old system or upgrading to a new system. This approach looks at the maintenance costs, downtime costs, implementation and any other hidden costs for both the old system and the upgrade process.

1.4 Methodology

The research aims at addressing the following questions:

1) When is a distributed control system due for replacement and what are the common motivating factors for a DCS upgrade/migration? An analysis of the projects undertaken by some of the DCS vendors on the market will be done to establish what motivated their clients to upgrade their DCS. A case study of Kiira Power Station with old control systems will be done to establish the failure rates and trends of the old control systems.
2) What are the upgrade strategies that can be used to upgrade an existing DCS? From the vendor projects, the approach used to upgrade or migrate the client’s DCS will be analysed taking into consideration the challenges and advantages attained.

Answers to these questions will be obtained by analysing and comparing the approaches taken for the DCS upgrade case studies from some of the DCS vendors on the market today. The data collected will be categorised into complete system upgrade and phased system upgrade. For each approach, the merits and demerits will be established.

1.5 Thesis overview

This thesis attempts to address the fore mentioned concerns in six chapters with **Chapter 2** entailing the literature review. A typical DCS is analysed, looking at the architecture of a typical DCS and related challenges faced by industries using legacy/old control systems. This is followed by upgrade strategies available for DCS networks and a cost benefit analysis of old network versus upgrading them in **Chapter 3**. To illustrate the strategies, a case study of Kiira Power Station DCS highlights the failures and upgrade solutions or strategies to consider in **Chapter 4**. A cost benefit analysis is applied to determine the best DCS maintenance and upgrade strategy for the power plant is carried out. Analysis of the research findings is done, future works as well as recommendations to consider are stated in **Chapters 5 and 6.**

CHAPTER 2: BACKGROUND

2.1 Hydro power plant overview

A hydro power plant of any size and complexity is basically made of turbines, generators, breakers, transformers and subsystems installed with numerous field instruments, operator interfaces, valves and other devices used to run the plant reliably and efficiently (figure 1). The components are connected and controlled by a DCS; a collection of processers/controllers and input/output (I/O) systems capable of making everything work together. The controller control logic related to individual generating units include: stop/start sequence, circuit breaker operation, reactive and active power control, control of temperature, communication to protection system, energy calculation and annunciation system.

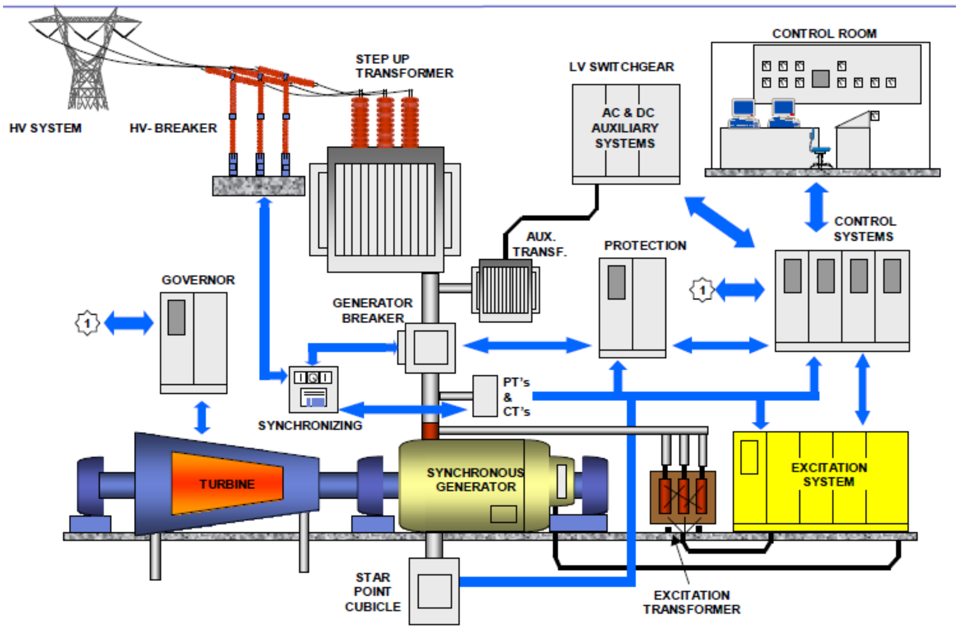


Figure 1: Typical power plant layout [6]

A DCS is designed to control field devices and process computers that are geographically distributed across the process plant or industry. A very fast communication network is used to connect the operator computers and field devices to these controllers. An example of field devices on the network are sensors and actuators which are connected to the I/O modules of the controllers. Figure 2 shows a basic layout of a DCS network that is made of a local area network, general purpose computer, data highway link, local display, local control unit, field devices and a data acquisition unit.

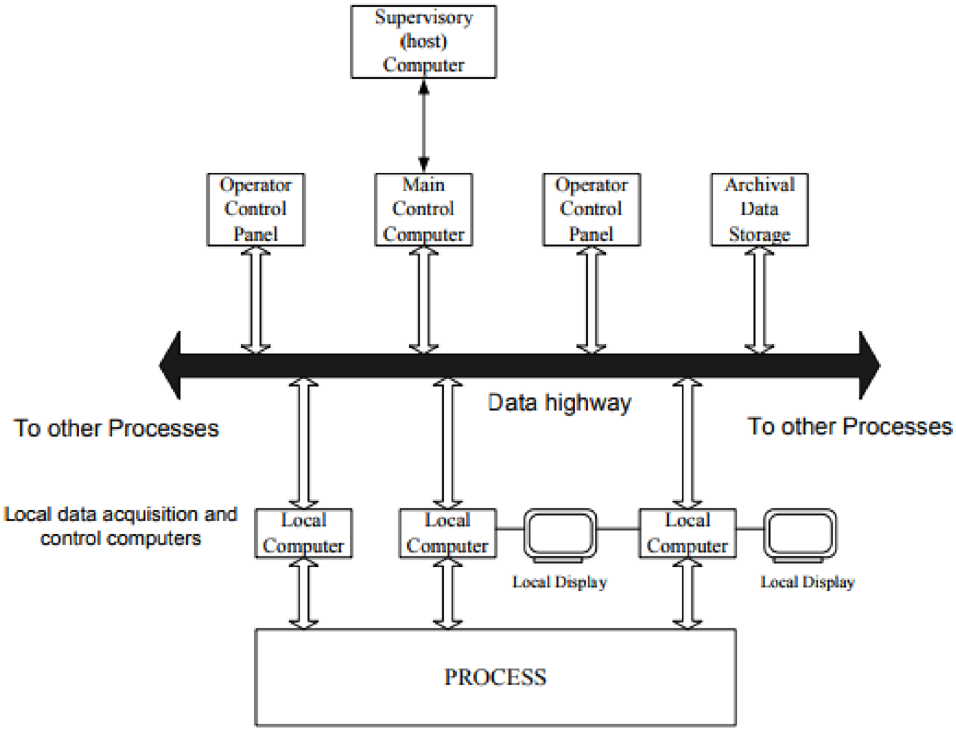


Figure 2: DCS Network layout [7]

The DCS enables control of the generating units from the operator station in control room, from local HMI or manually on the unit control cubicles. The DCS is thus designed to ensure that supervision and control of all major power system equipment can be done from control room (remotely) ensuring frequency and voltage stability, optimizing and fault-finding tools, coordination of generators and enabling local viewers support.

Critical as the DCS is, most power plants have their controllers as old as their civil structures, that is, their DCS platforms may be over 25 years of age [8]. In terms of computing power, these systems are extremely slow. Studies from different vendors show that such power plants have updated parts of their networks except for the controllers/processors and most of the input and output hardware is ancient. Figure 3 shows a comparison in terms of the civil structure and DCS component lifecycle.

For many of these power plants, if the DCS is working and the power plant can be dispatched, no plans are made to upgrade the system. They thus take on the approach, ‘if it not broken, do not fix it’. This is escalated by lack of skill to interrogate the systems thus few or no diagnosis is done on the network. Maintaining an old DCS may hinder the plant from realizing its full operational efficiency and streamlining business decisions with clear information.

Since the system may take long to fail, the company keeps the old DCS running until the electronics degrade, giving way over time. This then puts the business into panic state and a sudden massive investment to get the system up and running. The old control system platform and instrumentation increase the risk of failure and production interruptions and lack many of the capabilities of newer systems for improving plant performance.

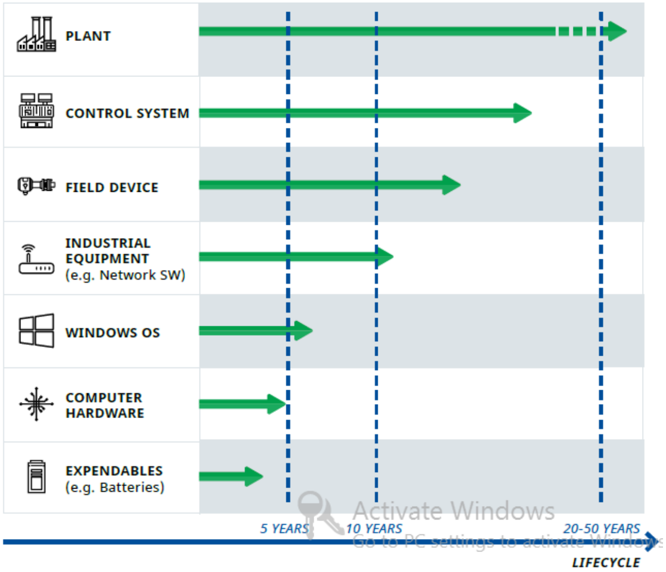


Figure 3: Life cycle comparison of power plant civil structure to the DCS [9]

According to ARC advisory group in their release, DCS worldwide outlook [10], $65 billion of installed process automation systems globally are nearing the end of their lifecycle which in many cases exceed 25 years. Additionally, over $12 billion worth of original DCS has been installed since the 1970s. Spares from auction sites over the internet may unknowingly introduce unexpected effects in the critical systems. The possibility of unsafe operating conditions, unplanned outage and financial loss far exceed the replacement cost of a discontinued part.

2.2 Risks associated with legacy/old DCS

To a plant and/or operations manager of a hydro power plant, the major risk associated with the old DCS is production down time. However, there are numerous risks and Table 1 identifies the top five risks including their consequences to the business and plant.

Table 1: Risks associated with using an old DCS [11]

	Risk	Impact	Consequences
1	Inefficiency in operation	Inability to embrace current best practices Operator mistakes resulting into lower production quality and downtime	Lower product quality Increased downtime Increased operator stress
2	New applications and systems not integrating with the existing	Key data not easily available to decision makers Full potential of new systems and applications not realized	Non-optimized operational performance Slowed business decisions Higher project implementation and ongoing support costs
3	Components unavailability	Prolonged outages System functionality loss Maintenance requirements increased	High maintenance costs Loss in production Production quality compromised
4	System failures	Increased down time Lower reliability	Increased forced outages Production loss
5	Reduced/unavailability of system support	Trouble shooting maintenance issues is difficult Prolonged timelines for projects requiring engineering troubleshooting	Increased maintenance and engineering costs Benefits of projects involving control system configuration are delayed.

As the failures on the system increase, the DCS becomes unreliable so does the power plant. Such defects that impact plant dispatch will force both the technical and management team to consider system upgrade as well as devise interims to address the situation.

2.3 Motivation for DCS upgrade

As the DCS ages, numerous factors make it difficult to maintain the existing control system. As such the business must investigate options of system upgrade or replacement. The factors discussed below are among those that should be considered to motivate for a DCS upgrade/replacement. These factors greatly impact the cost of maintaining the existing system as will be highlighted in this section.

2.3.1 System obsolescence

The major factor driving DCS upgrade is system obsolescence and its adverse effects. When production and support of system components is closed by the OEM due to numerous factors like upgrade of system versions, technical support and system spares become scarce [11]. It is thus important to keep in touch with the OEM to establish any plans of migration of their products. Planning an early migration before end of life of the system will eliminate panic, reduce time, plan production better and have ample time to effectively plan the project [12] [13].

Lack of knowledge on the legacy systems: as versions of the DCS are upgraded by OEMs over the years, there is a tendency of scarcity of skilled resources to handle the legacy/old versions of the DCS. This can be attributed to layoffs, retirements and promotions of personnel skilled in that product. As such, technical support becomes hard to come by thus the need for upgrade.

2.3.2 Advancement in technology

Legacy DCS lack openness for expansion or integration with newer systems. These systems are not compatible with new technologies that allow connectivity via open standards. As such, the old systems do not communicate effectively with third party systems. It becomes very difficult and costly to integrate newer systems with the older ones due to integration limitations. Secondly, the old DCS had proprietary networks customised to the different DCS vendors. As such, it is difficult or even impossible to connect other systems like historians and optimisation systems on these networks. New control systems support open-standard communications like HART, Foundation Fieldbus and OPC.

2.3.3 Maintenance cost

Rising maintenance costs of the old systems: with time, the cost of retaining the old system becomes higher than migrating to a new one. This is attributed to the expensive support and spare parts due to their scarcity on the market. This is one of the reasons Arkema Group, France, a chemical producer [14] decided to migrate from Honeywell TDC 3000 DCS to ABB's 800xA DCS, as the system was nearing its end of life time and spares were becoming expensive. Plant reliability will decrease, the number of unplanned shutdowns will increase resulting into production losses.

There is a general perception that older systems were more robust and last longer than modern systems. However, maintaining the legacy system has a high cost implication despite replacement parts being available for many years from third party vendors dealing in obsolete control. The price of obsolete parts increases as the components become scarce making replacement of obsolete system a high cost venture not withstanding extended downtime and increased failure rate of system modules.

2.3.4 System reliability

The failure rate of electronics changes over time. Following the Bathtub curve, the failure rate of new instalments is relatively high but if well tested by manufacturers, the initial failure rate will be minimised. During the recommended active lifecycle, and depending on the stress and working environment, the failure rate stays low for approximately 15 years for electronics/ eventually. As the equipment ages and moves through the wear-out phase, the failure rate increases. If the equipment operates into the wear-out phase, the risk of trip and unplanned down time is elevated.

2.4 Cost justification for upgrade/migration

2.4.1 Total Cost of Ownership (TCO) [15] [16]

TCO considers the cost of the DCS over its entire lifetime and provides information useful in decision making regarding the best maintenance and life cycle management of the system.

Considering a DCS upgrade or migration, the following costs will be covered under the TCO [17]:

1. Hardware replacement, new I/O modules and termination, controllers, networks interface modules, network switches, power supplies, HMIs, printers, to mention but a few.

2. The software will include: operating systems, engineering software, HMI, alarm management system, process history
3. Engineering, programming, installation and commissioning labour
4. Training staff at both operation and engineering level
5. Stocking spare parts

TCO common to the old and new system will include:

1. Maintenance, re-engineering and troubleshooting costs
2. Failed cards replacement, computer hardware and software upgrade
3. Technical support from the OEM, warranties, service contracts for software and hardware
4. Start-up costs and penalties from unit trips directly caused by control system failures
5. Revenue loss due to control system related down time

Table 2 shows how to calculate the TCO of a new system as well as old system. It has been broken down into four categories:

1. Initial cost/project cost-once off
2. Regular and ongoing operational costs-per annum
3. Regular service and maintenance cost-per annum
4. Anticipated downtime-per annum

Table 2: Calculating TCO

TCO Calculator				
Product name				
Lifetime expected of product:		**A**		
Product expense	**Items costs**	**Cost per unit**	**Quantity**	**subtotal costs $**
Cost category 1	Total initial costs for purchase (once-off)			

	including tax			
			Subtotal 1	**$0.0**
Cost category 2	Ongoing regular operating costs per year			
			Subtotal 2	**$0.0**
Cost category 3	Annual regular maintenance and service			
			Subtotal 3	**$0.00**
Cost category 4	Anticipated downtime (per annum)			
			Subtotal 4	**$0.0**
Summary				
	Expenses	**Total costs over entire life (Subtotal * life expectancy)**		
Category 1: initial purchase costs	**Subtotal 1**	once-off thus not applicable		
Category 2: regular ongoing operational costs	**Subtotal 2**	A* **Subtotal 2**		
Category 3: regular service and maintenance	**Subtotal 3**	A* **Subtotal 3**		
Category 4: Anticipated downtime	**Subtotal 4**	A* **Subtotal 4**		
Summary of expenses / income				
Total initial costs	**Subtotal 1**			

(**TIC**)	
Total expenses over entire life (**TEL**)	A*(**Subtotal 2+ Subtotal 3+ Subtotal 4)**
TCO	**TIC + TEL**

2.4.2 Calculating anticipated downtime-cost, category 4

To obtain the cost of anticipated down time, there is need to predict the probability of generating unit trips due to control system failure, using the mean time before trip (MTBT) and mean time to fail (MTTF) of control system component.

$$\lambda = \frac{n_{failed}}{t * n_{installed}} \quad (1)$$

Where:

- λ is the failure rate per hour
- N (failed) is the number of component failures during assessment period
- n (installed) is the number of components installed on the control network
- t is the hours taken for the assessment.

Mean time between failures (MTBF) is given by:

$$\text{MTBF} = \frac{1}{\lambda} \quad (2)$$

$$\text{MTBF} = \frac{\text{MTTF}}{installed\ count * trip\ probability} \quad (3)$$

MTTF is the mean time for a component to fail. Summing up all the component failures and multiplying by the unit measure of revenue cost gives the total cost of anticipated downtime.

2.4.3 Net Profit Value calculations

One of the ways to justify for an upgrade/migration as well choose which strategy to adopt, an economic case study must be done. The cost analysis can be done using several financial tools, however for the case of this thesis, a Net Profit Value (NPV) is considered. Usually where the projected return on investment exceeds the Total Cost of Ownership (TCO), then it is easy to justify and motivate for a project. Due to variations in costs of ownership, the net cash flow will be considered variable and the table 3 will be used to compute the Net Value (NV) and NPV. A project with a positive NPV is considered an economically viable at the given cost of capital.

Table 3: Calculating NPV

Cost of capital	**N%**		
Year	**0**	**1**	**2**
Net cash flow (TCO)	(A)	B	C
PV factor	E=100%	D=100 / (1+N %)	E=D / (1+N %)
PV of net cash flow	(A)*E	B*D	C*E
Cumulative PV	(A)*E	(A)*E + B*D	(A)*E + B*D+ C*E
Net present value	(A)*E + B*D+ C*E		

CHAPTER 3: UPGRADE STRATEGIES

Depending on the justification of the upgrade, a strategy must be decided upon how to upgrade the system. The upgrade majorly considers software and hardware upgrades. Under software upgrade, the instruments, computers and other hardware is maintained, but the software is upgraded to a newer revision. Under hardware upgrade, the field devices are maintained but the hardware and software of the control network is changed. The system could be upgraded all at once or in phases as defined below:

3.1 Replace the entire system

Replacing the entire system including hardware and software is the easiest option that can be undertaken. This implies that the HMIs, control hardware, input/output modules are all replaced with new ones. This approach is usually more expensive and usually requires a longer downtime than the phased approach.

3.2 Phased approach

Most of the DCS vendors on the market have well laid out strategies on how to migrate their products in phases. This approach allows for less downtime and has less inherent risks [18]. The price in the short run is cheaper but cumulatively more expensive. The advantage is that the cost is spread over a long period of time. Replacement of the system in phases and these can be:

Phase 1: supervisory layer components upgrade

In this phase, the HMIs are replaced with the latest model with the advantage of allowing for configuration of the legacy control systems onto the new one HMI packages that support OPC. With this phase, the upgrade can be done with the process running imposing less impact to production during the conversion. This phase allows for the operators to get acquainted with the technology before complete system installation.

Phase 2: Controller upgrade excluding the I/O modules for some OEMs.

Most of the new DCS products are compatible with the old controllers' input and output devices. This implies that the rewiring of the field components is eliminated and can be done later. This way, change of the I/O can be done at the flexibility of the plant shut down planned schedules. Likewise, labour costs are reduced as no rewiring is required and the original system documentation is retained.

Phase 3: I/O modules upgrade that involves replacing the input and output modules of the DCS system.

The field devices are usually left in place unless they are quite old and subject to frequent failures. Field wiring from the I/O to the field devices also stays unless it is in a very bad shape. Replacing wiring in an existing plant is highly expensive.

3.3 Vendor selection

Once the upgrade strategy is decided, there is need to select the DCS to migrate to and thus which vendor will execute the project. The following guidelines could be considered.

3.3.1 Maintain the existing DCS vendor

DCS vendors today have migration strategies for their systems and will therefore provide a migration plan for execution. For instance, ABB AC410 [19] was migrated to AC450 and now AC450 is being upgraded to AC800M all of which are well planned and communicated by ABB to its customers. For this option, it is very important that the vendor provides a solution that is new and still in active production, therefore a life of plant plan is very essential. For a phase approach, the vendor must guarantee compatibility of the new system with the existing and avail room for future migration of the rest of the system. Maintaining the vendor simplifies the application migration process of the control strategy.

3.3.2 Change DCS vendor

MS Windows-bases systems engaged in the 1990's architecture changed significantly from the older proprietary systems even within a given system vendor. Sometimes there is no justifiable reason to remain with the same vendor. Look out for the company legacy and evaluate their technology and features. Vendors that do not have the ability to stay long in the competitive market soon close and thus their products become obsolete. Consider how often a product line is changed as once a new product is released, some vendors terminate support and spares for the old system and will force you to migrate with them. This approach may not work well for a phased approach since the latest technologies use open systems that the legacy systems do not. It may be very expensive to interface the new vendor product with the old.

Advantages of migration

- New systems are highly adaptable, modular, built on open platforms and are more flexible than old systems
- Avoiding un planned shutdowns
- Improve price/performance ration
- Improved networking and interconnectivity
- Easier to integrate with enterprise systems
- More sophisticated HMIs
- Stronger cyber security
- Able to interface with smart field devices
- Better self-diagnosis capabilities
- Improved operational performance and decision making
- Network IO offers both hardware based flexibility and software based configurability

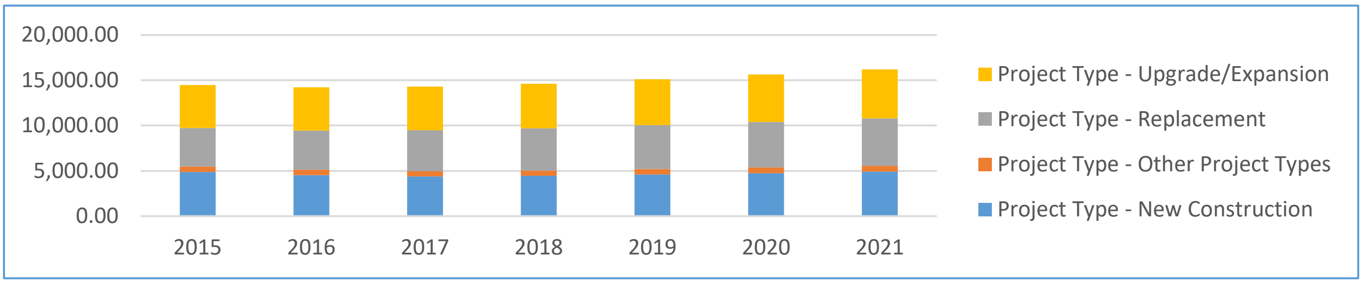


Figure 4: Total cost of projects by DCS vendors on the Market as per 2016 survey by ARC Advisory group *[20]*

3.4 Case studies

According to a DCS market survey [20], $65 billion of installed process automation systems in the world today are nearing the end of their lifecycle which in many cases can exceed 25 years. Major projects are happening to upgrade/expand and replace the old systems as shown in figure 4. ABB is the leading DCS vendor on the market (figure 5), thus case studies are taken from ABB.

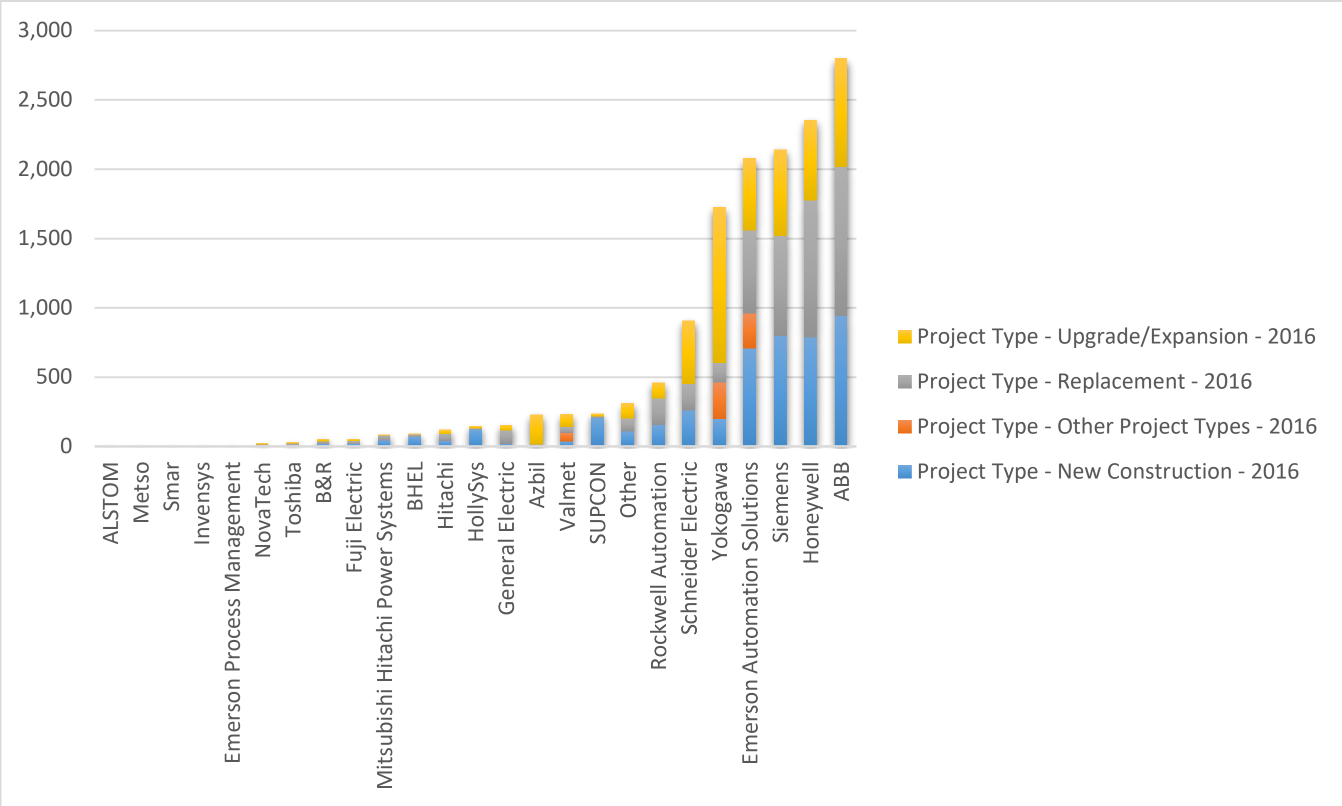


Figure 5: Market share in USD per DCS vendor as per 2016 survey by ARC Advisory group *[20]*

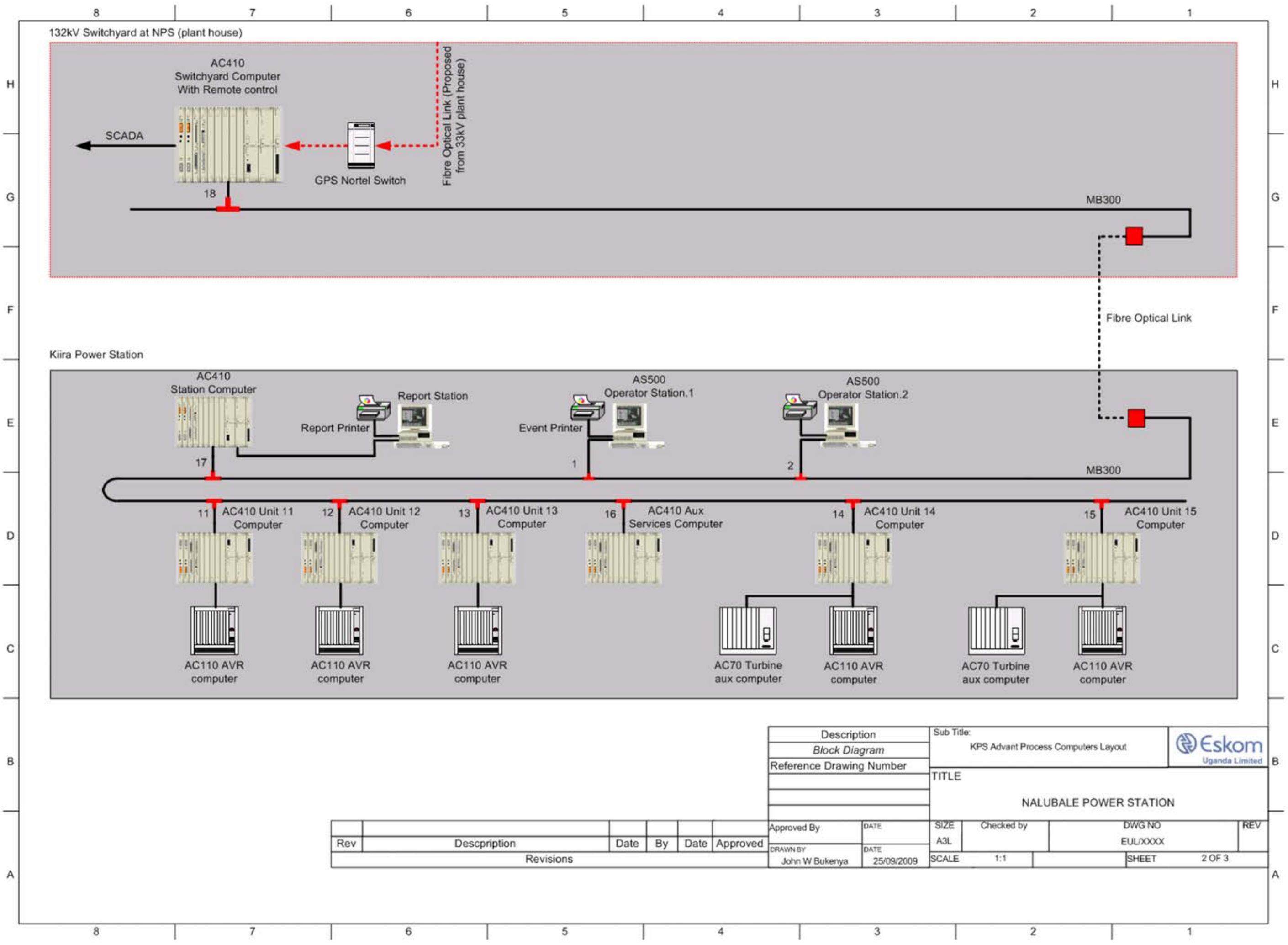
Table 4: Case study of DCS upgrades done by ABB

			Reason for upgrade			**Option adopted**	
	Case study		**Obsolescence**	**Scarce spares and support**	**Need to increase capacity**	**Phased upgrade/ migration**	**Complete Replacement**
1	Bregott Factory, Sweden: from Sattline system to 800xA system [21]	Production control system overloaded. Loop holes in information transmission. Upgrade improved system capacity thrice the original	TRUE	TRUE	TRUE	TRUE	FALSE
2	Langkawi Cement Plant Malaysia: from Polysius DCS to 800xA [22]	Obsolete system with scarce spares. Need to improve safety, efficiency and sustainability. Realized 10% reduction in energy consumption	TRUE	TRUE	TRUE	TRUE	FALSE

3	Baramati Agro Sugar Production, India: Siemens DCS to 800xA [23]	Daily production hampered by inconsistent automation system behavior. Throughput increased by 25%, plant availability increased to 15-20%. Man power cost reduced by 50%	FALSE	FALSE	TRUE	TRUE	FALSE
4	Argentine Brewery: Symphony DCI to 800xA [24]	Need to expand the network and increase capacity, and system reliability	TRUE	FALSE	TRUE	TRUE	FALSE
5	SSAB Tunnplat, Lulea Sweden: ASEA Master Piece 200/1 to AC450 [25]	CPU load at 80% limiting growth, need to increase productivity: CPU load reduced to 30%	TRUE	TRUE	TRUE	TRUE	FALSE
6	Arkema Chemical St. Auban France: Emerson Provox DCS to ABB 800xA [26]	Obsolete controllers (MUX, PCIU, DCU), high cost of Provox keyboard repairs	TRUE	TRUE	TRUE	TRUE	FALSE

CHAPTER 4: KIIRA POWER STATION (KPS) DISTRIBUTED CONTROL SYSTEM

Kiira Power Station (KPS) Distributed Control System (DCS) is based on ABB ADVANT Controller (AC) series (figure 6). The distributed processes Computers are performing the actual process control and process interface.



4.1 Unit computers

The Unit Computer (figure 7) is used for supervision and control of the generating Unit. The Unit Computer is of type Advant Controller 410 (AC410), a medium sized programmable process controller and member of the Advant OCS family, for binary, regulatory and supervisory control. The ABB MasterPiece Language (AMPL) is used for application programming. AMPL is a function-block language with graphic representation, which is especially oriented towards process control. The unit computer system comprises: Central unit, Local input/output system, Mechanical design, Power supply, Software, Fault detection and Communication links and interfaces.

Figure 6: Architectural layout of KPS DCS of the Power Plant.

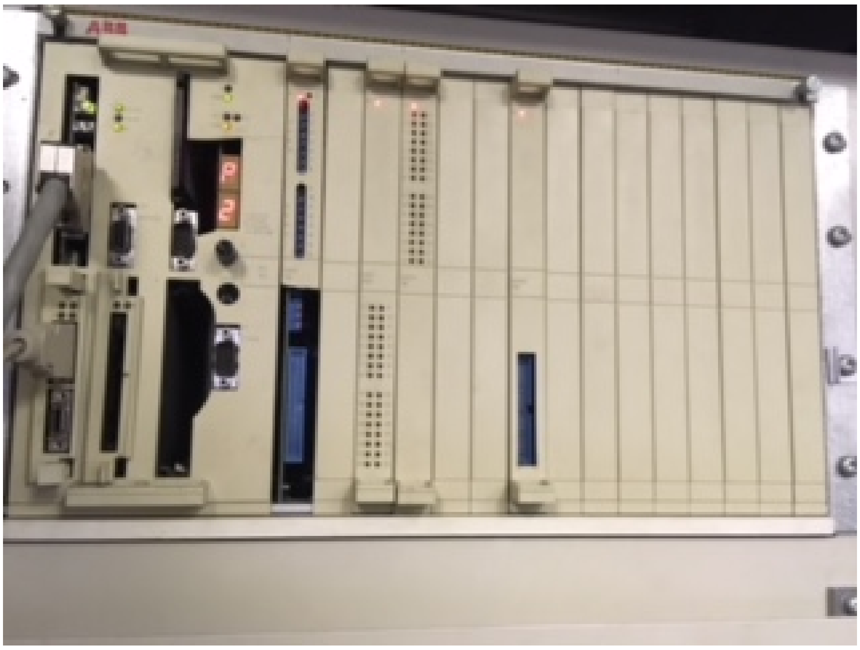


Figure 7: AC410 unit controller with I/O modules

4.1.1 Central Unit

The AC410 central unit is built around a high performance 32-bit microprocessor. The system software is stored in flash PROM. Application software is stored in Random Access Memory (RAM) with battery back-up. Application programs are executed cyclically on three priority levels. Cycle times are selected depending on the application.

Several supervisory functions automatically monitor system operation, which report and indicate any detected fault. The supervisory functions include; a real-time watchdog, back-plane bus supervision, memory checking and power supply voltage supervision. Faults are indicated by LED's on the relevant boards and by system error messages reported to the OS. The messages can also be read by the Advant Station 100 engineering station connected to the Unit Computer.

4.1.2 Local Input/output System

The local I/O system of AC410 can consist of up to 15 I/O boards, or about 450 I/O channels. Each I/O board has 4 to 32 channels, depending on type. The process cables are terminated on the connection units located in the rear plane of the cubicle. The terminals are disconnect-able individually so that the I/O channels can be isolated from the process for trouble shooting and test purposes. One or several connection units correspond to one I/O board. The connection units are provided with additional terminals for power distribution to sensors and actuators. The connections between connection units and I/O boards are by means of prefabricated cables.

Digital, I/O boards are provided with LED's indicating the status of each channel. The analogue input boards are provided with a LED indicating the successful completion of each A/D conversion. Diagnostic functions are executed for all I/O boards at system start-up and during normal operation. Any fault detected is indicated by an LED on the relevant I/O board and by a system error message reported to the OS. The message can also be read by the Advant Station 100 engineering station connected to the Unit Computer.

Application programs have access to the process variables via the database. This database also contains all I/O system configurations. The I/O boards can be exchanged while the system is running. New boards can also be inserted live, provided they are pre-defined in the database.

4.1.3 Mechanical Design

The Advant Controller 410 process computer is fully modular with circuit boards mounted in 19" sub racks. The Unit Computer is housed in one cubicle. The CPU sub rack contains the central unit and a voltage regulator unit. Empty boards’ position in a sub rack are occupied with dummy or shield board (to achieve correct ventilation). The connection units are fitted to mounting bars located in the rear plane of the cubicles. Each bar normally houses two connection units for I/O boards.

The Unit Computer is installed in cubicles of type RM518. The cubicle is of tropical design with degree of protection IP41 according to IEC 144. The cubicle is painted in a light Grey colour RAL 7035. It is equipped with a hinged frame, in which the 19" sub rack, power supplies, etc. are mounted.

4.1.4 Power Supply

Power supply is required for the Unit Computer and the process interface. The Unit Computer is provided with a DC/DC voltage converter supplied from the 110 V DC system. The output from the power supply unit is 24 V DC.

The process interface uses a DC/DC voltage converter supplied from the 110 V DC system. The output from the power supply unit is 48 V DC. A power switch unit, mounted in the rear plane of the cubicle, is provided to connect the Unit Computer to the mains supply and for distribution of voltage to different units in the cubicle. A mains power outlet is provided at the bottom of the cubicle for supply of an Advant Station 100 engineering station.

4.1.5 Software

The software in an AC410 process Computer is divided into system program and application programs. The system program is internal and links together the application program with the system hardware and internal program functions. The application program consists of one or more Process Control (PC) programs and the database. The PC program is written in a function-oriented, graphic high-level language, ABB MasterPiece Language (AMPL). A user of the process Computer normally only encounters AMPL and definition of parameters for the database. The application program can be documented automatically in graphic form on a printer connected to a tool for application programming, an Advant Station 100 engineering station.

The database in an AC410 system is a structured storage form for data, which is used by several internal program modules. The data base contains the data for the process I/O. For instance, for all analogue inputs, data such as measured value, scale factors, limits, process-related unit, dead band, etc., are stored in this structured form. It also contains data used for other functions, e.g. data transmission and data exchange between PC programs.

4.1.6 Fault Detection

The system executes many internal tests of the memories, processors, etc and some of these are only performed at start-up whereas others are in continuous operation. Faults on individual boards, such as I/O boards, result in disconnection of the board, illumination of a red LED on the board and the presentation of an error message. Single-line system messages are also generated that can be utilized for further fault tracing when the reasons for malfunction are complicated.

Faults in the computer's common central parts, such as the memory stop the system trip the watch dog relay, the contacts of which are available on the power switch unit mounted in the rear plane of the cubicle.

4.1.7 Communication Links and Interfaces

The Unit Computer communicates with the other process Computers and with the workstation of the control room via a control network. This network is a serial data link of type Master Bus 300 (MB300). The Unit Computer is connected to the MB300 physical link by means of a communication unit. The communication unit is connected to the coaxial cable of the control network via a connection unit, a transceiver cable and coaxial transceiver. The Unit Computer is also connected to the Excitation and Turbine auxiliary computers via the Advant Fieldbus 100 (AF100).

4.2 Turbine Auxiliary computer

The turbine auxiliary computer system comprises of one Advant Controller 70 (AC70) which is one of the smallest in the Advant family. It communicates with the Unit computer by means of the AF100. The computer and its associated input/output modules and power-supply are installed in a wall mounted control box. The door of the box is equipped with switches and pushbuttons for manual initiation for some of the controlled equipment, lamp indicators for pumps running is also available on the door.

The intention of this system is to perform automatic operation of the controlled equipment, by exchanging orders and feedback signals over the AF100 network with the unit computer. In local mode it is possible to give some orders and receive feedback from the door of the box.

The following equipment is controlled from this box.

- Hydraulic power pack for turbine control including some emergency operation of the system.
- Water supply for the shaft seal box.
- Automatic operation of the wicket gate locks.
- Automatic operations of the head cover drainage pumps.

4.3 System defects

Failure on the KPS DCS is largely attributed to age given that it was designed for a lifecycle of 10 years and has served for 17 years now. Among the system defects on the network is the "MB300 Checksum errors" in System alarm list at HMI engineering station. Each Checksum error means collision in network, reflection from oxidized connection between coax cable and terminators or because of EM interference.

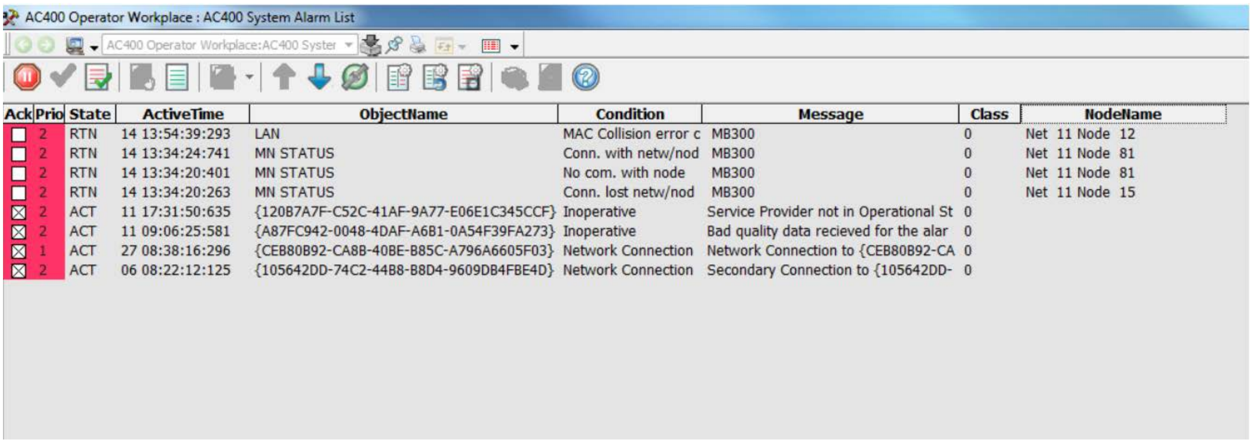


Figure 9: Communication errors on MB300 network

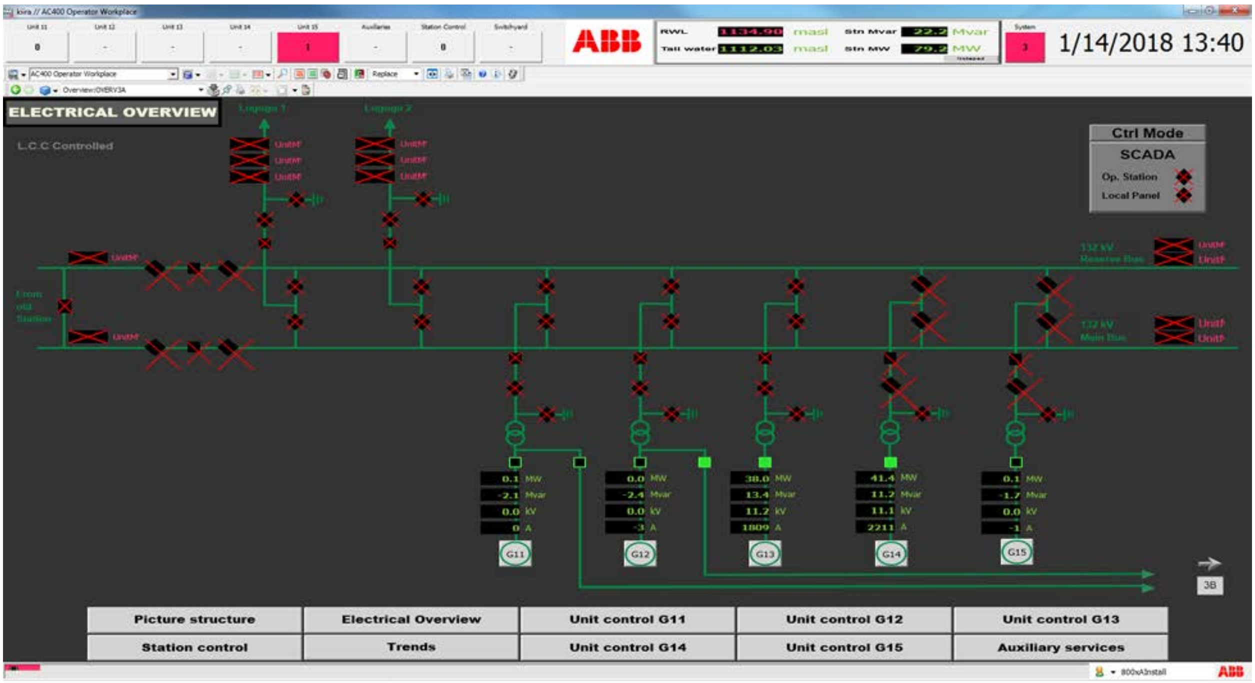


Figure 8: Graphics indicating communication errors on the network

One Checksum error per week is not a problem, but several Checksum errors per hour is a serious problem that must be solved soon. Due to failure of the switchyard AC410 controller 2km away from the generation plant, there are red crosses in HMI displays meaning lack of MB300 communication between the station computer AC410 and switchyard AC410 computer as well as the 800xA HMI system.

Further network investigations included connecting to each AC410 one-by-one in Online builder to check system messages. The CPU load of each AC410 in Online builder was investigated using the command ANPER, selecting graphical recording with one second update. It was noted that the system load is greater than 90% implying that the AC410 is heavily loaded and should be upgraded, Using the ABB Service Product Data Collector tool to diagnosis the network, the results show that the MB300 network has communication errors between AC410 controllers.

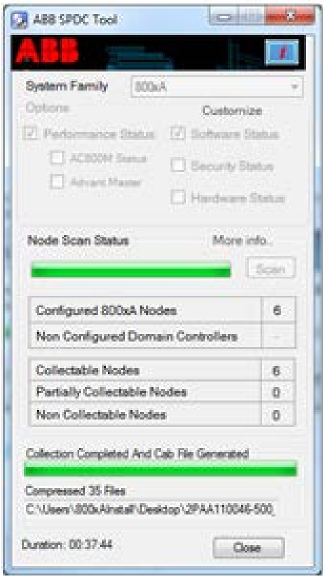


Figure 11: ABB SPDC tool
used to diagnosis the network

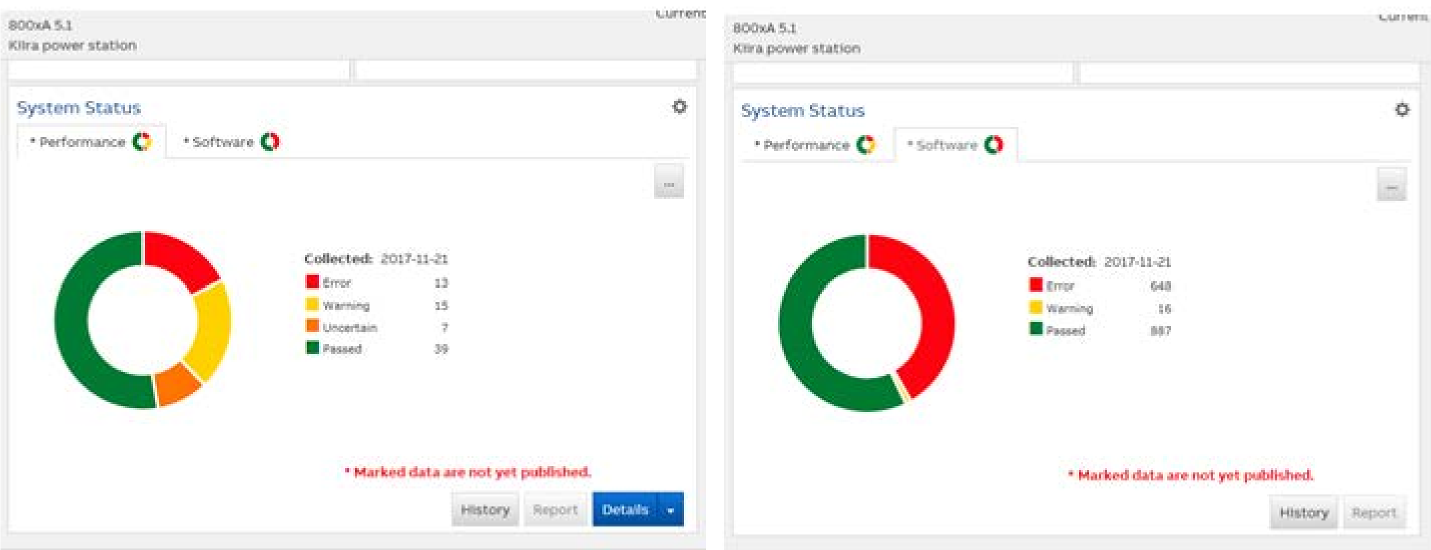


Figure 10: Results obtained from diagnosing the network

4.4 Spares availability

Spares for replacement are not readily available as the AC410 controllers are now in the limited phase as declared by the OEM. This means engineering and spares support is not readily available. As such, one of the AC410 controllers has stayed out of service for over one year awaiting the upgrade project. These AC410 computers were installed in 2000 and according to the manufacturer's Life Cycle Management and Master Plan for ADVANT Open Control System, this version of the current ADVANT controllers, was declared obsolete in 2009. Obsolescence of a product in the manufacturer's context means, it is no longer being manufactured, no Engineering support and not even refurbished units can be obtained. Other defects on the DCS network include:

- The AC410 computers' cards, though still operational, look physically deteriorated due to age. Given that there are no spares in stock, the system is rendered very unreliable.
- In October 2017, unit 12-unit controller program wiped itself out rendering the unit unavailable for over 6 hours. The program had to be rewritten by EUL Engineering team.

From the first quarter of 2016, the switchyard computer went into error state disabling communication from the switchyard to LCC and KPS. As a result, LCC is no longer monitoring the dispatch from KPS and the KPS operators cannot monitor the 132kV switchyard isolators and circuit breakers. There are few defects reported on the unit and auxiliary computers, however, benchmarking on the defects observed on the station and switchyard computers that are also AC410 and installed at the same time, these computers need to be replaced.

4.5 Advant Lifecycle

The ABB life cycle management model divides a product's life cycle into four phases: active, classic, limited and obsolete.

Active phase: the end user benefits from warranty options and a full range of life cycle services, spare parts and maintenance materials. The transition to the "classic" phase is dependent on economic and technological reasons. **Classic phase:** the product is available for extensions and is still fully supported. The end users may start to evolve with ABB support to new technology by using upgrade and retrofit solutions providing improved performance and extension of the life cycle. This phase ends when the production of a product ends and the "limited" phase starts. **Limited phase:** the manufacturing of new hardware is no longer supported but hardware availability continues for a limited time. Obsolete components are not replaced with the same technology but with evolution solutions and the use of reconditioned parts increases. Service support is on special request and according to availability. Half year before the end of the “limited” phase, an obsolete notice is distributed, and the product goes obsolete after this period.

AC410 hardware was moved to the Classic life cycle phase in 2008 and currently moved to the Limited phase in 2016. The OEM urges customers using AC410 controllers to migrate to newer generations of ABB distributed control systems, the closest step being to ADVANT Controller 450 or AC800M where the application code can be preserved to 100% thus avoiding new FAT and commissioning.

4.6 Upgrade options considered

4.6.1 Replace the entire system

Replacing the entire system including hardware and software would be the easiest option to undertake. This implies that the HMIs, control hardware, input/output modules are all replaced with new ones. This approach is usually more expensive in the short term and would require a longer downtime than the phased approach.

This option would allow for over vendors other than ABB to bid and execute the project as the entire system will be as good as new.

4.6.2 Phased approach

In the phased approach, the project would be restricted to ABB as the existing MB300 network is proprietary to ABB. The main system controllers AC410 would be upgraded to AC800M, the latest ABB controller that is IEC61850 compliant. The migration would take the following steps:

1. Operator and Engineering station upgrade from AS500 to 800xA
2. Station and switchyard computers from AC410 to AC800M
3. Unit computers from AC410 to AC800M
4. Turbine auxiliaries from AC70 to AC800M
5. AVR computers from AC110 to AC800M

Phase 1: HMI graphics migration from AS500 to 800xA PG2

The Operator and Engineering station upgrade from AS500 to 800xA. The 800xA installation takes about 2 weeks. One graphic can be converted and manually fixed within 4-6 hours. Migration of graphics if special graphical libraries are used in AS500 (like RMC) is quite tricky. Thorough testing of translated code is highly recommended for smooth commissioning. There are 3 possible scenarios:

- It minimizes costs and expenses without testing: This case brings a lot of risk of surprises during commissioning. Most likely this scenario leads to shutdown extension and delays in production.
- Testing of translated code of new AC800M controllers in simulation mode at test field. The best option is testing with AC410 in parallel.
- The test of one AC410 should take at least 2-3 weeks to test all sequences, interlocks of motors, valves, direction of PID controls, communications...
- Shadowing is a parallel run of AC410 & AC800M controllers during production, sharing the same IO input signals. The purpose of shadowing is thorough comparison of output signals from old & new logic. If the shadowing is applied during migration, then the 8 AC410 controllers can be replaced by AC800M within one-week shutdown if original IOs are reused.

Phase 2: Hardware upgrade to AC800M

A thorough hardware detailed engineering consumes several months. There are several questions that must be answered before the upgrading process. First, whether the existing S800 will be used or whether the S100 IO cards will be used. If the decision made is that S100 IO cards should be used, then installation of new DSBC176 cards will be needed. Additionally, all the AF100 coaxial cables must be replaced with new Profibus cables. However, if Profibus cables are not there, then AF100 twisted pair cables may be used as well. Ethernet network replaces all the former MB300 bus. Fiber optic ring with AVV branded switches connection is highly preferred if the AC410 controllers are distributed in far locations.

a) Control logic migration

Instead of rewriting the code from scratch, there is Ampl2m dot com tool for automated translation of Advant controller's code to AC800M. Some of the benefits of this system include:

- Automated translation saves a lot of time and effort (it saves 60-95% of time required for manual translation "from scratch").

- If original code uses standard features of Valvecons, Motcons, Pidcons then automated translation produces nearly working code.
- It minimizes human errors and typos
- Automated conversion utilizes software solutions already verified in successful migration projects
- Translation tool performs code optimization in terms of bypassing spare terminals and dummy logic gates.

AC410 automated translation may take 3-4 weeks including all necessary manual fixes. The amount of manual workaround depends on how sophistically and tricky the original AC410 code was written. It is possible to convert AC410 by conversion tool Ampl2m. Automated conversion cannot do the complete AC410 software conversion due to significant difference with application handling between AC400 and AC800M. Manual programming and experience is an important part of the conversion process. Post-conversion manual job for one AC410 CPU may take 2-3 weeks depending on how tricky the original software is written. However, 3-weeks job is much easier than half year manual reprogramming AC400 to AC800M.

b) Communication network and compatibility

In the phased approach, at some point in time, part of the network will be old while the other is new. The control network communication is very different between these controllers (AC410 and AC800M). The AC410 runs MB300, a proprietary, but IEEE 802.3 compliant protocol (it uses Ethernet as media) while the AC 800M runs MMS, a somewhat more openly standardized protocol based on regular Ethernet IP and TCP.

The protocol specification is, at least in the case of MB300 proprietary. The upper (OSI) layers of MB300 has a lot in common with GCOM, which was more widely used. The lower layers are very different though.

MMS is simpler in its design (offering query/answer and write/reply methods) while MB300 has full bodied features for automatic routing, media redundancy, ordering, subscribing, on event delivery and prioritization.

The yellow coaxial cable can be upgraded to Ethernet structured cabling using Ethernet switches, metallic or FO cables, AUI/RJ45 converters at every AC410. The new system would use open communication networks that would allow expansion of the network and introduce the possibility of having other vendor products onto the network.

4.7 Justifying Upgrade Option for KPS DCS

Using the calculation indicated in section 2.4, the impact of having major components on KPS DCS obsolete can be analyzed as in the table below:

Table 5; Trips per year attributed to KPS DCS faults

Component	**Installed count**	**MTTF (hr)**	**trip probability**	**MTBT (hr)**	**trips per year**
AC410 Controllers/computers	8	21,563.1	0.8	3,369.2	2.6
AC110 Controllers/computers	5	87,600.0	0.8	21,900.0	0.4
AC70 Controllers/computers	2	56,940.0	0.65	43,800.0	0.2
Power supply modules	20	700,800.0	0.4	87,600.0	0.1
Digital I/O modules	250	1,095,000.0	0.1	43,800.0	0.2
Analogue I/O modules	200	876,000.0	0.1	43,800.0	0.2
Network interface	20	140,160.0	0.2	35,040.0	0.25

Each unit generates 40MW and a unit of power is USD 10 per MWh. On average, it takes at least one hour to restore a unit after a trip. For cases of network failure, it is possible to have a multiple unit trip that could result in losing the five units. Thus, the least revenue lost per year due to trips caused by DCS failures is USD 400 and for a multiple unit trip it costs USD 2,000 (5*40*10).

The total number of trips per year as per the table is 3.96, thus assuming 1-hour restoration time, for a single unit trip, the revenue lost is USD 1584 and for multiple unit trip is USD 7,920.

However, due to lack of readily available spares, it can take at least one month to get a spare or technical support from the OEM, this puts the revenue loss to USD 1,178,496 (31*24*1584) and USD 5,892,480 (31*24*7920).

Table 6: TCO calculation for maintain the current KPS DCS

TCO Calculator				
Product name		Existing obsolete system		
Lifetime expected of product:		10		
Product expense	**Items costs**	**Cost per unit/$**	**Quantity**	**subtotal costs $**
Cost category 1	Total initial costs for purchase (once-off) including tax	500,000	1	500000
			Subtotal 1	**$500,000**
Cost category 2	Ongoing regular operating costs per year	0	0	0
			Subtotal 2	**$0**
Cost category 3	Annual regular maintenance and service	31,000	5	155000
			Subtotal 3	**$155,000**
Cost category 4	Anticipated downtime (per annum)	1,584	5	7,920
			Subtotal 4	**$7,920**
Summary				
	Expenses	**Total costs over entire life (Subtotal * life expectancy)**		

Category 1: initial purchase costs	500,000	once-off so not applicable
Category 2: regular ongoing operational costs	0	0
Category 3: regular service and maintenance	155,000	1,550,000
Category 4: Anticipated downtime	7,920	79,200
Summary of expenses / income		
Total initial costs (**TIC**)	**500,000**	
Total expenses over entire life (**TEL**)	1,629,200	
TCO	**2,129,200**	

Table 7: TCO calculation for upgrading the DCS

TCO Calculator				
Product name:		Upgraded system		
Lifetime expected of product:		10		
Product expense	**Items costs**	**Cost per unit/$**	**Quantity**	**subtotal costs $**

Cost category 1	Total initial costs for purchase (once-off) including tax	2,000,000	1	2000000
			Subtotal 1	**$2,000,000**
Cost category 2	Ongoing regular operating costs per year	1,000	1	1000
			Subtotal 2	**$1,000**
Cost category 3	Annual regular maintenance and service	1,000	1	1000
			Subtotal 3	**$1,000**
Cost category 4	Anticipated downtime (per annum)	1,584	0	0
			Subtotal 4	**$0**

Summary		
	Expenses	**Total costs over entire (Subtotal * life expectancy)**
Category 1: initial purchase costs	2,000,000	once-off so not applicable
Category 2: regular ongoing operational costs	1,000	10,000
Category 3: regular service and maintenance	1,000	10,000
Category 4: Anticipated downtime	0	0
Summary of expenses / income		

Total initial costs (**TIC**)	**2,000,000**
Total expenses over whole-of-life (**TEL**)	20,000
TCO	**2,020,000**

Table 8: Comparing TCO for 5, 10 and 15 years of old system versus upgraded system

System	**TCO 5 years**	**TCO 10 years**	**TCO 15 years**
Obsolete system	1,314,600	2,129,200	2,943,800
Upgraded system	2,010,000	2,020,000	2,030,000

4.7.1 NPV analysis for old system versus upgraded system.

Table 9: NPV for obsolete/existing system

Interest rate	**Year**	**Cash flow**	**PV factor**	**PV of cash flow**	**Cumulative PV**	**Net Present Value**
12%	0	(162,920)	100%	(162,920)	(162,920)	(278,524)
	1	(162,920)	89%	(145,464)	(308,384)	
	2	(162,920)	80%	(129,879)	(438,263)	
	3	(162,920)	71%	(115,963)	(554,226)	
	4	(162,920)	64%	(103,539)	(103,539)	
	5	(162,920)	57%	(92,445)	(195,984)	
	6	(162,920)	51%	(82,540)	(278,524)	
	7	(162,920)	45%	(73,697)	(73,697)	
	8	(162,920)	40%	(65,801)	(139,497)	
	9	(162,920)	36%	(58,751)	(198,248)	

Table 10: NPV for upgraded system using complete replacement approach

Interest rate	**Year**	**Cash flow**	**PV factor**	**PV of cash flow**	**Cumulative PV**	**Net Present Value**
12%	0	(2,000,000)	100%	(2,000,000)	(2,000,000)	51,287
	1	30,000	89%	26,786	(1,973,214)	
	2	30,000	80%	23,916	(1,949,298)	
	3	30,000	71%	21,353	(1,927,945)	
	4	30,000	64%	19,066	19,066	
	5	30,000	57%	17,023	36,088	
	6	30,000	51%	15,199	51,287	
	7	30,000	45%	13,570	13,570	
	8	30,000	40%	12,116	25,687	
	9	30,000	36%	10,818	36,505	

From tables 9 and 10, the net profit value for the upgrade is positive while that of maintaining the old system is negative over a span of 9 years. It can also be seen from table 8, that the cost of maintain the old system is 31% higher than that of a new system. In conclusion, the best solution is to have the system upgrade.

CHAPTER 5: DATA ANALYSIS

Approaches in evaluating upgrade projects sometimes are faced with wide range of challenges. Business owners require the system upgrade strategies to be cost effective with the ability to deliver return on investment. Therefore, it follows that, any system to be replaced must have a superior performance in respect to reduced life cost as well as improved functionality to advance in new opportunities and technologies. Additionally, to ensure a sustained investment in a newly invested technology, it requires that accurate strategies to measure investment are laid down [27]. This will reduce problems associated with capital projects which seem to be increasing in the recent economic environment.

Obsolescence is one of the methods which the power station can use to justify its DCS upgrade systems [28]. However, this technique cannot deliver the best justification when used alone. Therefore, obsolescence can only be used when it is the only method accepted by the company policies. In circumstances where an equipment experiences repeated failure of shut down or prolonged outages, like in the case of Kiira Power Station, obsolescence may indicate the need for upgrade systems. Besides, unless the system has a long history of shutdown problems with a substantial risk, it may be difficult to prove to management that there is a need for an upgrade system. Therefore a cost benefit analysis has to be done and usually the cost of maintaining an old system supersedes that of upgraded the system in the long run. According to the projects executed by ABB, the leading DCS vendor, most businesses will adopt a phased approach instead of a complete system replacement as a whole.

Considerably, an ideal case for justifying upgrade systems should be founded on clarity and must ensure multi-layered cost considerations [29]. This will ensure that the cost associated with keeping current system is accounted for. In addition, this cost can be compared to the profit accrued from new system within the same period. From tables 9 and 10, it can be seen, that if KPS maintains status quo, then the cost of operating the network will be much more that upgrading the network. From tables 9 and 10, the net profit value for the upgrade is positive while that of maintaining the old system is negative over a span of 9 years. It can also be seen from table 8, that the cost of maintain the old system is 31% higher than that of a new system. In conclusion, the best solution is to have the system upgrade.

Determination of the cost of an upgrade is a stepwise procedure [30]. At the initial stage of the process, the scope for upgrade decision is determined. This is carried out through an accurate examination of the already existing control systems and variety of alternatives for upgrade alternatives available. For any available upgrade option, OEM can be used to measure the associated cost and provide the preferable alternative based on the estimated cost. Various cost decisions for control system upgrade is arrived at after considering wide ranges of estimates based on the cost of the components. Firstly, the cost for new hardware comprising I/O modules, HMI stations, desks, printers, cabinets, routers, I/O terminations and network switches is determined to form part of cost estimate component for control system upgrade. Secondly, analysis of the software cost as of the cost estimate is included in control system upgrade. It consists of alarm management, keeping process history, HMI, software for engineering and asset management [31]. Additionally, the cost for labour during commissioning and cost for labour used during existing system examination and succeeding engineering, operator graphics and reprograming is incorporated during the estimation. Finally, the cost for operation trainings, engineering personnel, and maintenance as well as the cost for spare parts for stockholding are estimated. These components form major constituents of cost estimate for control system that should be considered during cost estimation for system upgrade [32].

5.1 Choosing the Optimal Strategy

There are several upgrade options available as formerly stated. They all consist of types of upgrade as well as techniques for life cycle management. Every unit has a different life cycle management strategy. However, this will depend on the aim of each unit in the business. For example, the obtainable parts after upgrading high ranking units can be used in supporting lower-ranking units

Furthermore, there are units that may rank high in business profitability but at the same time have features of control systems that are outdated. These units require first upgrade before the control system becomes outdated if the business is not operating on high ranking units. Partial or full upgrade options can be considered for these units depending on the degree of obsolescence

In a company, arrangement of control system upgrades is based on the order of unit importance. To avoid problems associated with high ranking units, it is advisable that these units are moved up to prevent such problems. However, the company may apportion some amount of money to cater for upgrade. In this case, scheduling of the systems should be done as appropriate to the budget. Besides, the company may decide to minimize cost by the inclusion of third party. This involves upgrading parts of some units following severe issues and allowing the rest of the control systems to be given the third party as a support. This may happen until parts become too costly that the upgrade cost is justifiable. When this happens, the top-grade units are upgraded first, and the other remaining parts are used to complement lower ranking units [32]. Also, no upgrade option is only applicable to units scheduled for decommissioning and therefore enough spare parts should be availed for them.

5.2 KPS Upgrade Strategy

Given the deterioration in network communication and performance as well as the DCS controllers being rendered obsolete by the OEM, the cost of maintain the current DCS is expected to be much higher than upgrading the system, needless to say the financial loss attributed to multiple unit forced outages due to DCS failure. The best option for KPS DCS upgrade is the phased one; first, refurbishment of DCS console system so that the system achieves the best performance. Then change the controllers in phases as shown in section 4.6.2 with new controllers, the communication network can be upgraded; AF100 bus is to be replaced by Profibus and MB300 bus replaced by Ethernet network. It is however not clear whether it is possible to upgrade the system without having to shut down the system [21].

CHAPTER 6: CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The KPS upgrade project has to proceed as most parts on the network are obsolete. The upgrade will reduce the risk of loss of income, production downtime. Since the option recommend is a phased one, it would be prudent to use the existing OEM to avoid incompatibility issues. Engineering will take a shorter time as the OEM is conversant with the old and proposed new system. It has been demonstrated that maintain an obsolete system is more expensive than upgrading in the long run. According to the case studies done, a system becomes obsolete when spares and technical support from the OEM become scarce, the capability of the system to expand becomes limited as well as failure to integrate new technology on the system.

Majority of legacy system have come to a point where it is no longer effective to proceed work using conventional process control systems. The old systems have customised protocols are not compatible with the latest technology. They also have limited capacity, lack spares and technical support. Furthermore, Process Management has made strong approaches for migration of legacy systems which gives room for a step-wise transition to new architecture. The DCS OEMs have designed frameworks to smoothen the upgrade process for their obsolete systems. Thus business like KPS can deploy the OEM for an assessment of the best alternative to take for the transition [33].

A flexible phased approach to migration is a vital element for success for almost all process automation supplier. The ability of Kiira cater for this ensures the company has the flexibility to replace specifically those assets that are logical, at the same time providing the end user with higher level functionality necessary from modern system. The solution indicates a compact grasp of migration concerns of customers. End users are able to assess the solution or combination of solutions which actually addresses their needs best.

6.2 Recommendation

Platforms for upgrading a control system range from small to large. When the larger part of the system has become obsolete, it is important for the company to upgrade the system incrementally. The incremental upgrade often changes from a full-rip-replace project if it is done on small-scale basis. In most cases, old systems are integrated and not designed with open structure. Therefore, the systems are difficult to upgrade because of the difficulty in changing the system parts. Therefore, there is need to consider more modern approaches which support evolutionary improvements by being modular than old systems [34]. During the course of this work, it has been noted that a lot of research has gone into studying obsolescence of IT system, but very few have focussed on DCS. Future works should consider developing models that can be used to predict DCS obsolescence and failure trends as well as other cost justification techniques beside total cost of ownership and net profit value.

REFERENCES

[1] L. O'Brien and D. Woll, “The control system migration survival manual,” ARC Advisory Group, Dedham, MA, 2010.

[2] D. L. B. W. J. G. V. W. Jesus Bisbal, *An overview of Legacy Infomation System Migration,* Dublin: Trinity College, Dublin, Ireland, 2006.

[3] E. B. Swanson and E. Dans, “System life expectancy and the maintenance effort: Exploring their equilibration,” *MIS Quarterly,* vol. 24, no. 2, pp. 277-297, 2000.

[4] C. Harper, Upgrading Your DCS: Why You May Need to Do It Sooner Than You Think, Maverick Technologies, 2010.

[5] S. P. Marchek, “A quantitative investigation of the technology obsolescence model (TOM) factors that influence the decision to replace obsolete systems (Masters Thesis),” Capella Univeristy, Minneapolis, 2015.

[6] ABB Ltd, Excitation system basics/J 990 Training, Turgi: ABB Switzerland learning center power electronics, 2005.

[7] King Saud University, “Process Control in the chemical industries,” in *Process Control in the chemical industries*, King Saud University, 2002, pp. 132-144.

[8] ABB, “Parts finger print service justifies upgrade of MOD300 control system for US Chemical Plant,” ABB, 31 8 2016. [Online]. Available: http://new.abb.com/control-systems/industry-specific-solutions/chemical/parts-fingerprint-service-justifies-MOD300-dcs-upgrade. [Accessed 4 02 2018].

[9] Yokogawa , DCS Migration Strategies: Everything you need to know about control system migration, Califonia: Yokogawa Corporation of America, 2017.

[10] D. Clayton, “Distributed Control Systems Worldwide Market Outlook,” ARC Advisory group, 2017.

[11] M. Little, “Distributd control system lifecycle management: Guidelines for planning and managing the lifecycle of distributed control systems,” Electric Power Research Instituite, Califonia, 2013.

[12] A. Basahel, “A framework for evaluation of strategic information system planning (SISP) techniques,” in *BBS Doctoral Symposium 23rd and 24th March 2009*, London, 2009.

[13] Nigel James, Mangan Inc, “Control System Migration: Reduce Costs and Risk by Following These Control System Migration Best Practices,” 2009. [Online]. Available: http://www.controlglobal.com articles/2009/ControSystemMigration0901.html?page=full. [Accessed 24 June 2017].

[14] L. G, “Planned Obsolescence and product lifecycle,” *Applied Mechanics and Materials,* vol. 371, no. 1, pp. 857-861, 2013.

[15] ABB, “Honeywell TDC 3000 DCS migration to ABB's 800xA at Arkema chemical plant in Marseille,” ABB, 2009. [Online]. Available: http://new.abb.com/control-systems/industry-specific-solutions/chemical/honeywell-tdc-3000-migration-to-800xa-at-arkema-chemicals-france. [Accessed 24 June 2017].

[16] S. D. David J S, “Managing your IT total cost od ownership,” *Communications of the ACM,* vol. 45, no. 1, pp. 100-106, 2002.

[17] O. p. h. White G E, “Lifecycle costing,” *Management Accounting,* vol. 57, no. 7, pp. 38-45, 1976.

[18] P. Dan Hebert, “Best Practices in Control System Migration,” June 2007. [Online]. Available: http://www.controlglobal.com/articles/2007/006.html. [Accessed 24 June 2017].

[19] ABB, “Advant Controller 410 for MOD300 DCS,” ABB, 2007. [Online]. Available: http://new.abb.com/control-systems/service/customer-support/advant-mod-300/as-mod-300-controllers/advant-controller-410-for-advant-mod. [Accessed 25 June 2017].

[20] A. A. Group, “ARC-MIIRA Distributed Control Systems-WW-2016-Excell,” ARC Advisory Group, 2016.

[21] ABB, “The “whey” to efficiency - Seamless technology switchover to System 800xA at Bregott factory,” ABB, 2012.

[22] ABB, “Polysius DCS upgrade to System 800xA for Lafarge cement plant in Malaysia,” ABB, 2012.

[23] ABB, “Siemens DCS migration to ABB's System 800xA at Baramati Agro,” 2010. [Online]. Available: http://new.abb.com/control-systems/industry-specific-solutions/food-beverage/replacing-siemens-with-abb-system-800xa-at-baramati-agro. [Accessed 03 02 2018].

[24] ABB, “System 800xA: Argentine brewery upgrades active phase system,” ABB, 2010.

[25] ABB, “Evolution from MasterPiece to Advant controller for SSAB Tunnplåt steel plant in Sweden,” ABB.

[26] ABB, “Arkema St Auban evolves to system 800xA DCS family, ID 3BSE067239,” ABB, 2010.

[27] M. Brodie, “Migrating legacy systems: Gateways, interfaces and incremental approach,” *Morgan Publishers,* 1995.

[28] U. E. P. S. M. G. P. Bjoern Bartels, Strategies to prediction, mitigation and management of product obsolescence, Hoboken, NJ: Wiley, 2012.

[29] N. James, “Control System Migration,” *ControlGlobal.com*, 2009.

[30] M. N. P. P. Egon Berghout, “Management of lifecycle costs and benefits: Lessons from information system practice,” *Computers in Industry,* vol. 62, no. 7, pp. 755-764, 2011.

[31] “197 A distributed computer energy management and control system,” *Control Engineering Practices,* p. 572, 1993.

[32] J. Fujii, “DCS Evolution: The next generation DCS: Experion,” *Japan Tappi Journal* , pp. 1295-1298, 2013.

[33] “Mark IV to Mark VIE Migration gas turbine control system upgrade,” *General Electric Company,* 2005.

[34] ABB, “Symphony Harmony Distributed Control System Migration -Beneifts of evolution strategy,” *Letter Power Generation,* 2011.

[35] D. Hebert, “Best practice in control system migration,” *ControlGlobal.com*, 2007.

[36] ABB, “Arkema St Auban evolves to system 800xA DCS family,” ABB, 2010.

[37] ARC Advisory Group, “Emerson's Flexible Approach to Control System Migration, White Paper,” ARC Advisory Group, Dedham MA, 2008.

[38] M. S. Gupta, “Customers Discuss Successful System Migration Projects,” in *Emerson Exchange Americas,* Denver Colorado, 2015.

[39] Nigel James, Mangan Inc, “Control System Migration: Reduce Costs and Risk by Following These Control System Migration Best Practices,” Rokewell Automation , Milwaukee, 2009.