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A standards-based service oriented architecture design for substation fault detection

Said, Ebrahim Yassir

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A STANDARDS-BASED SERVICE ORIENTED ARCHITECTURE DESIGN FOR SUBSTATION DETECTION

Ebrahim Yassir Said

A dissertation submitted to the Faculty of Engineering and the Built University of the Witwatersrand, in fulfilment of the requirements for the Master of Science in Engineering.

Johannesburg, 2012

DECLARATION

I declare that this dissertation is my own unaided work. It is being
of Science in Engineering to the University of the Witwatersrand
submitted before for any degree or examination to any ot

.....

(Signature of Candidate)

....17th.....day of .May.....year.2021.....

day month year

ABSTRACT

Reliability and security in power supply is a measure of how well a
a consumer at a given point in time. Achieving high levels of reliability requir
expenditure. A power system is therefore required to operate at optimal capacity in
return on capital investment. In order to attain a high level of reliability in the
there is a need to implement processes in power systems to deliver
of failures to protect components connected to the grid. In South Africa, grid has aged and
traditional infrastructure that supports consumers is unable to
requirements. To ensure the continued growth and refresh of grid
committees have established standards and guidelines that chal
substation systems architecture. Reference process architectures
information exchange standards have gained support from vendors over
last decade. A growth in the number of implementations of these s
for system integration and interoperability is high and future. This
demand and applicability to emerging systems architecture approa
architecture considered in this dissertation. This dissertation standards, design patterns
emerging frameworks to fault detection. In order to deliver
the fault detection process, a set of UML representation of the detection
requirements. UML is for model driven design in software enginee
proposes design rules of software components that are flexible, ext
detection information to support reliability protection. Also, model
implements the final application to indicate the placement of specific co
reference architecture used in this dissertation.

The aim of the dissertation is to prove that an application for fault detection
modular, reusable and flexible in design by using existing soft
architecture design principles.

Keywords: TM Forum NGOSS, IEC 61850, COMTRADE, Service Oriented Architecture, Fau
Detection

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GLOSSARY OF TERMS

Term	Acronym
Business Process Modelling Notation	BPMN
Enhanced Telecommunications Operations Map	eTOM
International Electrotechnical Commission	IEC
Intelligent Electronic Device	IED
The Institute of Electrical and Electronic Engineers	IEEE
International Telecommunication Union	ITU
Next Generation Operating Systems and Softw	NGOSS
National Institute of Standards and Technology	NIST
South African Bureau of Standards	SABS
Smart Grid	SG
Shared Information & Data Model ®	SID
Service Oriented Architecture	SOA
Tele Management Forum	TM Forum
Unified Approach	UA
Unified Modelling Language	UML
Extensible Markup Language	XML
XML Schema Document	XSD

CHAPTER 1
INTRODUCTION

1.1 Introduction

A key requirement for interoperability should be technology neutra
the development of bi-directional information flows for emerging initiatives [1]

In order to meet desired levels of return on investment, power systems connected
required to run at optimal capacity. These operating levels are no
load conditions for consumers. The nature of any system is that it
to provide some redundancy and capability. However when poorly
exposes the system to multiple points of failure. Properties of measu
failure in a system, providing the necessary reliability and redundancy.

All processes, including fault detection, require timely and accurate, data and info
operate correctly. Information is therefore required at a low later
devices [2]. All of these requirements need highly available, fast and r
as the automation of substation requirements. The latter is
and central substation data [3].

Legacy systems architecture is an issue when attempting to create
issues are resolved to an extent by the advent of smarter device
research shows that devices and modern networking technologies
part in automation and integration [4]. This indicates that there is c
interest in the interoperability of functions and processes, as well as the
information. To ensure the continuation and refresh of grid te
committees have established standards and guidelines that aim to
substation integration. Strategies position a utility for emergi
initiatives like Smart Grid and Cloud Computing. These initiatives
due to financial and environmental viabilities.

Research indicates that the following problems exist [2] [3]: for integratin

- Data Structure: The large number of different formats of device
  ability to integrate data into a substation central store;
- Size: The processing and assessment of one device event for in
  exclusion from device function. The volumes of data will increas
  devices are introduced;

- Quality: Although data is generated by device, there may be
  malformed data that will adversely affect the function it is me
- Latency: Substation information is required at very low latenc
  protection functions, but at a higher latency for post fault ana

Continued demand for substation integration means that more proto
methods will become available. Some of these will perform under spe
specific conditions. The large number of electrical process compo
of configurations means that it is necessary for devices to support int
like tight coupling in devices, hardwired systems, vendor specif
embedded device processes cause issues with replacing current s
expected, legacy systems architecture documentation that is dated h
upgrade costs. Delivering integrated substation environments must be a measurable, effective
efficient. This requires loose coupling, standards, common process
information interfaces.

Results of a global market survey indicate that an increasing numbe
average, increasing expenditures on capital assets, operations and
change spending across areas like SCADA, energy managemen
integration and transmission infrastructure. Figure 1 shows the average of the percentag
respondents are changing their spending between 2011 and 2012.
the utility companies engaged in the survey will increase their ca
2% increase from the number of respondents in the 2011 survey. An
companies will increase their operations and maintenance budget
fewer utilities are decreasing or maintenance spending from 2011 to 2012.

Figure 1. Power system capital, operations and maintenance spending for
Source: Capital Expenditures, Operations & Maintenance Budge[4]

An investigation into expenditures of utility companies indicates that the following cate
of interest on their budgets for 2011 to 2012.

- Advanced metering;
- Distribution automation;
- Distribution transit; structure
- Protection control;
- SCADA/energy management systems/ratio management systems;
- Substation automation/ratio and
- Transmission infrastructure

Figure 2 indicates the percentage of survey responses from utilities f
dissertation. The shows a weighted view of the spending substation movem
automation and integration, protection and control.

- The percentage of utility companies increasing spending between 2011 and 2012
- The percentage of utility companies decreasing spending between 2011 and 2012

- The percentage of utility companies having the same expenditure between 2011 and 2012

Figure 2 Capital, operational and maintenance expenditure for automation, protection, control. Source: Capital Expenditures, Operations & Maintenance Budget [4]

An increase in the number of respondents that capital spending for protection and control will increase 2011 to 2012. A 7% increase of respondents indicated 2011 s this 8% more respondents confirm that their capital expenditure for subst integration will stay the same. The survey also indicates that decreasing the irwi expenditures on automation, protection and control initiatives.

The survey shows that technology, software and other items that can focus capi most utilities over the next two years. These reflect the physical assets, and no workforce.

Researchers are currently engaged in delivering automation and control through interoperable environments. This is found in work by several re Kezunovic et al. from Tex A&M University [2][30][32]. The area of fault-critically detection is of particular interest in this dissertation. Key research t

its inherent overlap with protection and control activities. To pick a dictionary, the internet and seam
wide access to data supports fault analysis research as the gro
information for grid operation is a sensitive utility industry.

As expected, the systems engineering industry has as well and
different approaches for designing and implementing software systems. The ri
and cloud computing has a reliable interest by both academics and v
information that has previously been embedded in utility operations no
being exposed to consumers and other interested stakeholders.

The aim of this is to propose a framework for delivering reu
software components needed for creating and consuming integrat
considered for issues like alarm processing and event analysis. Wide and even Valley's indi
that data exchange through information knowledge supports substation efficienc
effectiveness [5]. Understanding and management of data requirement
management of utility infrastructures.

1.2 Scope

Effectiveness and efficiency of power flow regulation into homes
indicators that can measure the reliability of a power system. Severity of a power system
reliability in South Africa. Tsk, operation information exchange standards for t
South African Grid published by the National Energy Regulator [6-8]
These standards include fault reporting, information requirements
One of the key requirements for analysis is a bility information within 15
minutes from when a disturbance. The substation [6]. Event data acquisition from process
component to substation gateway is however not an one set. The [8]. Tone position taken in
this dissertation is that devices generate real time information and
design scope for the provide station operator access to data. This respective
means that the operator will have a access to a liable data

The power grid is a network of components that operate to provide a ut
of power consumers. The analysis and processing of power system require the knowledge o
experts in the areas of generation, transmission and distribution architectures. E
sub domains like transmission and distribution protection enginee
area are vital to meet the power system s requirement of a provid
power to consumers. Economies have many constraints dependant on
specific service levels and are thus sensitive to changes in leve
create a more reliable infrastructure and a need to protect the curre
whilst refreshing the ageing infrastructure to cater for future need

The aim of this dissertation focus on the substation, and components wi connecting node in the larger power grid within the context of the dissertation define a fault as a set of disturbance events that constrain the operating execute in a subsystem. This dissertation further investigates the substation as a group o cohesive components that produces strategic, tactical and opera provide needed visibility of externalised processes across clear provide access to information in a substation disturbance. The substation environm requires visibility for real time monitoring, protection and contr complex nature of the data, substation data, effective management of data, information substations proposed supports growth the data and information [illegible]

Industry bodies have aimed to produce standards that well cover and the implementation of newer technologies in substations. Technical communications that panels consisting of the same vendors that require integration standards. This dissertation focuses on the implementation of a fault using da collected from substation components. Interconnection standards that have a direct be design, information exchange and protection requirements.

1.3 Research Hypothesis

The previous section provides an overview of the problem and scope. The following sec the research hypothesis:

To investigate the ability of a fault analysis framework from the communication utility industries to deliver a service-based application for analysing events from two e faulted transmission line application to perform analysis function, using in substation data. To assess the flexibility of the design changing application requirements driving the change though a requirements traceability process

1.4 Research Method

The research method for this dissertation focuses on identifying existing resea focus of specific research topics and generating specific research opini areas are used to deduce a general design of the specific implementation investigated together with industry research in the areas of service or standards. The best possible method for the information between components invol detection is processed

1.5 Objectives

The objective defined of information that traverses a service. Specif design patterns implement a designated substation data. The outc

an application design containing a model driven approach for analysing substation components within the context of a power system node level. Nodes are system components that interconnect the power sys

1.6 Layout

Chapter 2 discusses the standards that are dissemination. Threat and fault detection. Chapter 3 explores the architecture and components req analysis. This chapter positions the building blocks that will cons software components. Chapter 4 outlines an implementation use case of the fau detection process. The chapter also delivers the deployment view with an alternati flexibility in the design. Chapter 5 provides concluding remarks for the work efforts in the area of substation information integration

1.7 Conclusion

This chapter is an introduction to the research that has been performed. It outli problems with substation environment. Chapter 1 positions the research of a key driver in substation integration and automation. The objective larg and research method proposed will result in the architecture flexible software engineering pattern

CHAPTER 2
STANDARDS

2.1 Introduction

Standards are a result of combined efforts by organizations to dri agendas for technology and infrastructure implementations. Stand guidelines, procedures and processes that are applied in a specif [9]. Standards bodies orchestrate interactions between organizations. Examples of these bodies are the TeleManagement Forum [10] and the International Electrotechnical Commission [9]. Consortia like the Tele Management Forum ha development of process and information standards for the telecom has recently branched out into areas other than communication, the area of military defence has shown, but more specifically utilities and the focus of some activity. Since the Last Mile, Sunrise, Ethernet, has developed range of standards for the electronic devices and communicatio devices.

The standards produced by these bodies play a pivotal role in the of this dissertation.

2.2 Standards

2.2.1 Tele-Management Forum NGOSS

The Tele Management Forum (TM Forum) is a company located in of America. The TM Forum produce, train and consult on standards for the service provider industry. The TM Forum launched 1988 to provide standards and interoperable network management systems. The forum released it after being established and in 2004 its process framework was Telecommunication. The forum currently has more than 700 members [10].

Over the last decade, the TM Forum and its partners have dev interoperability and standardization across enterprise business and technic frameworks are currently in use of business processing, information architecture and enterprise. Over time, frameworks have undergone the fundamental ideas introduced as part of the original designs processes that are present in most organi

Due to increasing requirements for organisms socially and financiall
the delivery of services, an organisation is ways of streamlining operat
leveraging existing business at its technology assets to provi
accurate basis for decision processes. Consortia like the TM Forum have
developing mechanisms for standards and information.

The TM Forum manages a set of interacting frameworks labelle
Systems and Software (NGOSS®) under the auspices of this. These are industry w
frameworks, methodologies and definitions [11].

NGOSS contains four domain specific sub frameworks. These ar

- The Enhanced Telecommunications Operations Map ® (eTOM) defines a work for business processes;
- The Shared Information and Data Model ® (SID) defines a in
- The Telecommunications Applications Map ® (TAM) define framework; and
- The Technology Neutral Architecture ® (TNA) defines an integration fr

Figure 3 references an online Forum of TM Forum [12]. The figure indicates
interaction between the domain specific frameworks. The focus
information components of the framework indicated by the d
architecture and architecture are specifically due to the ability of
frameworks to act as a map for the defining and specifying the sc

Figure 3 Interacting frameworks from the TM Forum Source TM Forum Framework [12]

In addition to these, the TM Forum's application programming (APIs), which support the creation of applications that are compliant to the latter. APIs are purposeful by due to the specific capability by the process information framework.

The structure of the selected frameworks enables multi entry points. This for system supports the ability to keep on the primary definitions of the each spe example, analysts with a strong preference can use the process frame determine processes that control specific information entities. An analyst with a information modelling can use the information framework to dete hierarchy. For this also, the implementation of a fault detection process means that the process framework is the point of entry.

The TM Forum process framework consists of number of vertical, ho components. By the very nature of the set of reference models and organizations that aim to implement any of the process standards reference model that are specific to their own requirements like AMDOCS publish versions of the TM Forum's framework [13]. Figure 4 is company simplified version of the framework from an online publication.

Figure 4: A simplified view of the TM Forum published by AMDOCS. AMDOCS Online Poster [13]

The process reference model enables vendors, implementers or a
project or implementation that they are engaged in. It aids in identifying gaps in re
as areas where they may be a possible. The reference architecture
levels of abstraction that makes communication of its content easi
figure 4 there are several process levels. Level 0 (zero) has two distinct
process areas namely:

- Strategy, Infrastructure: These process with the creation and
  management of the strategies provided by a service provider.
- Operations: These process with the enablement and building of the
  services delivered through a product (equipment) cycle.

The process framework delineates strategic, tactical and operatio
process levels stretches from level 3. Example of level 1 process are those that tra
all vertical or horizontal process groups, levels are the grouping
Product Lifecycle, Assurance and Billing processes. Level 2 captures the intersection
of a level 1 vertical and level 1 horizontal process groups. Example of these processes
found in Management & Inquiry Resource Trouble. Level 3 processes are
At the time of writing, the TM Forum are engaged in creating level 4 descriptions
the reference model. The presence of this work and the purposes fully
process and information frameworks selected dissertation definition available
process documentation classify the fault detection subsequent equipment
specifically.

The TM Forum has recently extended the material through its member dri
initiatives called catalyst programs [15][16]. Programs require the vertical and horizonta
layers of the process of a time scope as both strands have communication
requirements. One of the advantages of using a reference model
model are able to clearly delineate the scope within which a pr
reference model also provides a means to check for gaps in the de

This dissertation to reference the process framework in order to pro
fault detection process and attempt to change the levels or-defined of t
processes stipulated by the TM Forum

2.2.2 International Electronical Commission: IEC 61850

The International Electronical Commission (IEC) is a standards body that produce s
electronic communications and information devices. The commission
countries with 60 full members and 21 Sustainable Affiliate members [17] represented

South African Bureau of Standards (SABS) is a full member that powers the SABS voting rights on standards and access to technical documentation and IEC

Technical committees and technical subcommittees of the IEC are the committee develop and manage series of publications through structured workgroup for smart grid equipment interfacing is handled by technical com published by TC 57 focuses specifically in the areas of:

- Telecontrol Protection and Control Equipment
- Distribution Automation
- Communication Networks and Security
- Application and Energy Management System Integration

This dissertation uses the IEC 61850 standards due to the substation discussion. The IEC 61968 network operations interface standard produced by TC 57 that deals with fault-isolation. The IE communication standard that has been in existence since 2000 specific requirements for IEC 61850 management, substation configuratio modelling, data modelling, mapping to other IEC standards and indicates the publication structure extracted from the IEC standards lis

Table 1 IEC 61850 Document structure [19]

Reference	Domain	Short Description
IEC/TR 61-1	Substati	Introduction and Overview
IEC/TS 61-2	Substati	Glossary
IEC 61-3 85	Substati	General requirements
IEC 61-4 85	Utility Automati	Systems and project manag
IEC 61-5 85	Substati	Communication requirements for fun
IEC 61-6 85	Utility Automati	Substation Device Configurati
IEC 61-7 850	Substati	Principles and models for substati communication
IEC 61-7 850	Utility Automati	Abstract Communications Serv
IEC 61-7 850	Utility Automati	Information Model (Common Da
IEC 61-7 850	Utility Automati	Information Model (Logical Nodes
IEC 61-7 850 410	Utility Automati	Monitoring and control communica power plants
IEC 61-7 850 420	Utility Automati	Information Model for Distributed
IEC/TS 61-1 801	Utility Automati	Guideline for Information Exchange control centres

IEC 61-85	Utility Automati	Communication Service Mapping to O ISO/IEC Standard
IEC/TR 61-90	Utility Automati	Use of IEC 61850 for the communicatio
IEC 61-85	Substati	Communication Service Map Sampled values over serial-unidirec point link
IEC 61-85	Substati	Communication Service Mapping to ISO/IEC Standard
IEC 61-85	Substati	Conformance Testing

The need for a data model and associated interfaces exists due t devices that serve somewhat blurred functional boundaries. Devic complex integrated processes that require specialist skills to [2]. The aim of the 6185 standards is to provide needed visibility to externalised process clearly defined device functions. This is a compliance to the ISO/IEC Standard of abstract services components.

The dissertation refers to 61850 models with logical node and data classe information exchange between components. Reference models to communicate th dependencies between 61850 [5]. Figure 5 extends current model represent including constraints for data types though the introduction of at that data attribute has one domain. This means that the data is of a sp

Figure 5A Metamodel for IEC 61850 information model. Source: IEC 61850 Class Mode

The following definitions apply to figure 5

- Network: This refers to the physical transmission medium over sent;
- Physical Device: This refers to a physical substation device that communications network
- Logical Device: This is refers to a function specific physical devices.
- Logical Node: This is representative of a sub function or logical sp by the logical device.
- Data Object: This is a collection of attributes that describe the device
- Data Attribute: This is single characteristic of a data object.
- Attribute Value: This is specific that described attribute. For example, Boolean attribute have one of two possible values True/False

Logical Nodes IEC 61850 standard include Protection Functions, C References, Interfacing and Archiving, Automatic Control, Meterin Monitoring, Switchgear and Instrument Transformers. Transport of standard information between equipment of these categories

2.2.3 IEEE Std. C-37.111-1991 COMTRADE

The Power Systems Relay Committee of the IEEE Power Enginee common file format used for transient fault information. Then known as the IEEE Standard Common Format for Transient Data Exchange (COMTRADE) storage and not transported data [22]. This largely the 61850 standard can be used to create physical data structures the storage of fault infor format contains four key files used for storing fault information:

- A header file which was the .HDR file extension;
- A configuration file which has the .CFG extension;
- A data file which has the .DAT extension; and
- An information file which has the .INF extension.

Table 2 C37.111-1999 data file distribution Source [22]

Name	Type	Target	Requirement
Heade	Option	Plain Text	Data file information
Configur	Mandat	Plain Text	Defines data file
Data	Mandat	Plain Text or Machine Re	Contains sampled data
Informa	Option	Plain Text	Contains access re

The standard explores multiple representations of each file with format. Based on the file types and requirements, some these file and monitoring input, which defines a suitable structure of the information classes that form a configuration files.

Figure 6 Information Entities for COMTRADE [22]

2.3 Conclusion

Standards are a result of efforts by organisations to drive interoperability and agendas in technology and infrastructure implementations. Storage classification, transient and persistent information and information architectures from the IEC and IEEE. The implementation of standards are important to the architectures of telecommunication and utilities infrastructure. The dynamic utility and communication operations is vital in that the convergence of the standards. The success of convergence is measured by the interoperable models to be assessed with each other by placing constraint on the standards to align.

The dissertation uses three diverse standards to enable a coher information systems and communication environments. The position taken in this dissertat harmonise sections of each standard in order to deliver a set of specific guidelines set out by each of the standards.

CHAPTER 3
ARCHITECTURE

3.1 Introduction

This chapter deals with the scope and architecture, and requirements patterns needed to deliv based solution that enables flexibility and agility in the area of su delivery.

3.2 Wide Area System Requirements

In the United States, the National Institute of Standards and Technology (NIST) provides a view of a smart grid architecture outlining information and electrical flows. It also recognizes state the boundary of the service specific functions. The models us provides context only and does not represent how the proposed addition to the power flow from a utility s generation to distribut networks are linked to users that are internal to the utility as well a utility. This means that the smart grid connects power values derived from a conceptual model by the NIST model [1]. This model indicates that a secure information flow between all parties engaged in the power value chain over a Smart Grid model. Smart research shows that the trending need for the integration of data and information from disparate sources fou Distribution environments [2].

Figure 7 A conceptual information network for exchanging power system information for NIST Smart Grid Framework [1]

In the US, the NIST have outlined requirements for the implemen
protection and control environment. A key infrastructure component in the wide area
control environment are substation systems that enable fast c
exchange. A secondary substation control computer system, or data conce
able to communicate with the control centre that [2]. The substation
systems and communication links between the substation and the
redundancy and availability in order to meet low or medium latency
requirements. For example, a requirement of this system is to de
specific substation devices within threshold ranges.

In order to certify the integrity of the information across substation systems, s
that comply with IEC standards are deployed to substations to ens
information propagation. The IEC standards support substation communication
communication is sensitive to delays due to the bus connecting primary dev
equipment in the substation together. A network station wide bus
world over a wide area network via a secure gateway appliance
communication of this bus is marginally slower than that of the
monitoring system should support two types of information sources
across data stores. Synchronous and asynchronous affected nodes on the network. Data
two types:

1. Local to substation for low latency processes, activities and trips. For
   signals sent from a relay to a breaker.
2. Decentralized to substation for higher latency processes, activities
   post fault analysis processes for fault trending and equipment

There are constraints placed on distributed data for substation integration. Th
of content deploying different classes. The IEC compare [2]. The IEC compare the use of disk ve
file access methods with the mechanism suffering from I/O conten
provide faster access but come with a large management overhead
to reduce the identified overhead through specific file extension
standards. The IEC standards are used to check for the absence or presence of specific files
An example of this is the COMTRADE file extension. The IEC standards
[2].

In order to support local or distributed data storage patterns, a standard
data access component must be polymorphic. The dissertation focus
function call patterns in a multi-tier architecture specific functional requirements

Function call patterns are common execution delay paths that fault detection process.

3.3 Substation

Lusby defines a substation as an interconnecting component of [2,3]. Substations are at a point of isolating, transformation, control, or rectifying power grid. They are at the impact on this dissertation as they generate data and information required to the grid. There are several substation design patterns in use to safety factors are some of the variables that affect decisions rela are very complex entities that have multiple configurations, tooling requirements. They require special skills to manage and design.

An analysis process to decompose the main functions and information operations must be used to understand the exact requirements and impa into the substation environment.

3.3.1 Equipment

The generation and dissemination of timely information is vital to decision making. In substations, the accuracy and quality information is needed to inc decreasing safety and security risks [5]. Substation monitoring and control devices hardwired analogue interfaces to digital interfaces and microprocessor [2,3]. Intelligent Electronic Devices (IEDs) generate information in substations. An IED is defined as process-based unit which has at least one communications port capable control signals to enable specific functions [2,4,25]. Such functions that-support an interprocess and information flows create a logical to physical mapping of the enable [2,6].

Within the scope of the dissertation produced by Digital Fault Reco Digital Protection Relays (DPR), and Circuit Breaker Monitors (CB sources of data for the creation of a fault. Each substation device pr set of functions that supplies a set of information used in the anal operations. These device types interface with other components in or via feeds onto the file system of device with which i

Figure 8 is derived from a substation automation kaszt [2,7]. The figure indicates that a set of intended purpose for the data of the data and relationships between different buses in the substation. It indi substation sub systems, and by definition, the information flows b requirements for each of the varied latency.

Figure 8 Substation protection control flows and data flows in Substation Automation Interface [27] Source IEC 61850 Substation Automation Interface [27] Model

In figure 8, the substation station (substation 2) contain the substation wide o condition state data and information. Moving down the chain of data stores the availability of data increases to a real time view as the data need process real time actions. It should be noted that the control and data flo components in Figure 8 occur simultaneously. It is not a serial process. Du components normal operations generated both the data and the data that processed and analysed

3.3.2 Substation Operational Data Store

A substation operational data store is a local data store that hold devices that operate within the boundary. Depending on the requiremen in databases or as flat files, however, it is designed access and management protocols and user interfaces. Equal samples data files in .mdf format locally or distributed across a storage cluster.

A problem of varying data formats is a known [2][3]. The substation of rese data structures are required in order to integrate data, also dat known as transformations, can occur in the following scenarios [2][8].

1) Transformation could happen close to the intelligent electronic dev conversion to a common substation information model will c

software or software supplied by the device vendor. The dev
format onto the substation file server or substation master comput

2) The transformation could happen after the device has to deliver
the substation file server or substation master computer. This
computer would require a client service call to load the file, tra
export a file formatted in the common file format onto the serv

3) The substation device will use its native format in executing m
only transform the file to the format if the substation needs to con
transmission substations or directly with the control centre.

Certain designs use read event to indicate the data is due to a file
computer [29]. The application design proposed in this process considers an event as a pub
information message rather than continuously checking whether a file
system location.

The second and third scenarios are of particular interest as these
processes. However, each of the scenarios needs to be investiga
reusability. Standards should be compliant to COMTRADE for Pow
area of substation data concentration is the Research of many cases
centralization and classification [24] [29] [30]. This is by no means an exha
list of references. The use of integrated substation data cannot be un
substation evolution. Determining the type of warehouse or operat
subset of the broader enterprise warehouse, is driven by the later
basic protection or reporting.

An influx of information for analysis purposes is caused by an increase in the num
devices in substations and on the power grid holistically in cases of smar
requires that a focus on the growth of data and information stores. Si
methods provide a means of growth store calculation to
create a size forecast modeled by [31]. The model can be used
calculating individual tables, which include multiple table and variant grow
to be more. The numbers used in the calculation are 256 and 10 kbyte primary, for a period of 1.5 years for a single table.

Table 3. Calculating data storage size for a single Sin18[3e1]

	byte	kilobyte	megabyte	gigabyte
Row Size	256 b	0.25 Kb	0.0002 Mb 441	0.000000 Gb 2
Annual Row Count Min	500 000 000			
Annual Row Count	510 000 000			
# of Years	1.5			
Key Size	10 b	0.01 bK	0.0000 Mb 095	0.000000 Gb 0
	Minimum		Maximum	
Row Min/Max	750 000 000		765 000 000	
Total Minimum for 1	199 500 000	194 824 Kb 21	190 258 Mb 0	185.8 Gb 0
Total Maximum for 1	203 490 000	198 720 Kb 70	194 063 Mb 1	189.6 Gb 1

3.3.3 Architecture Boundary

Protection functions enable the grid to run at high-capacity fo implementing necessary safety and security controls to protect eq on fault, or to initiate protection resolution procedures, engineer access to accurate information. This reflects the detailed state of connected within the substation boundary. Research and warehou databases were and store event information. File systems and data w patrn used for substation in [3]. [32] The modern of automated substation f requires that integrated data is available for use by in the sub boundary. Generated event information by multiple applications via a file system or database link.

Using a process reference from the fault detection part of the Resource Troubleshoot Management in the process. This is a level 2 process figure of Chapter 4. The dissertation later discusses of this level 2 process.

The application design by the dissertation, analysts and planne disturbance data in the substation. Knowledge of the technicians correct physical location in which assupporting reliabi goals of the grid, the device substation can information affects the integrity. [28] Based on a numbers of possible data devices in the substation establishing and querying a master source detection. Fault analysis be delivered as a set of applications that master computer [29]. Composite fault services created to a shared environment within the substation.

The federation of data sources provides a way to decentralise management whilst still suppor consolidated information views. In future, the need to federate s sources will increase due to an increased number of information requir to support dynamic demand and supply modelling as well as other operations. The data and information supporting fault analysis operations and are justified as dependant variables in the calculat

Currently requirements for data integration span SCADA, specific clas measurement and intelligent device data are applied to different a [30]. Research in the areas of integration data still focuses on delive transformation. This actually means supporting warehousing and reporti which in turn require stringent availability and quality. The databa of a warehouse should be enable the ability to query information response times. The design of data structures for substation information s of flat tuning records versus records that have a high referential integ

The application design classifies data into four broad categories:

- Data that needs to flow between two devices in order complete
- Data that will be written to a file system or database;
- Data that will be retrieved from a file system or database; and
- Data requirements for calculation

The standards selected must support the following requirements:

- Mapping of the device outputs to the substation data store so
- Standards the target load process; and
- Increase clarity in analysis process by reducing complexity.

Table 4 indicates how the selected standards for the fault process support the stated data requirements.

Table 4 Analignment of TM Forum and IEC standards to support fault inform requirements

Requirement	Standard	Preferred nomenclature used this dissertatio
Substation device mapp	IEC 61-850	Device Information
Standardized file database landing	COMTRADE	Fault Information A
Enterprise wide uti process and activi	TM Forum eT	Utility Process Archit
Enterprise wide util	TM Forum S	Utility Information A

The fault detection process is a business process. A TM Forum and IEC t standards create a common understanding of the fault process top down bottom upper perspective. The following sub-sections report the selected mapping approach

- The utility process architecture will not require information mapping to architecture as both of these architectures by a single standar
- The IEC 61850 standard will undergo minimal change;
- Mapping of utility information architecture (SID) define the IEC and IEEE Standards ensure that standards are coupled to any formal mapping. Changes to any of the standards do not affect the standards directly.

The area of common information model is discussed currently by standards lik IEC 61850, IEC 61970 and IEC 61968. Whenever a number of soo implement similar technologies, the need for common information and decentralized warehousing and access to warehouses is information, data integration and implementation of common utility information through common infrastructure is supported by the creation of physical common infor [3]. Technology implementations like the Data Platform Information System (CIDPS) a China Grid Company Limited, is one such example. EUSEP through t 61970 standard for energy management, the principle regarding common information and integration within the subsidiation boundary

3.3.4 Architecture Patterns

An architecture pattern outlines a set of solve concerns to recurring pr Patterns exist for systems engineering problems. The decoupling presentation is such a pattern in Object Oriented program. For example, a language layered approach develops a three-tiered architecture that decouples components in an application design [5].

In the world of data management, software vendors focus on two d namely batch-time real. Conventional data warehouses use the proce transform the data into information and finally loading the data in difference between moving data for warehousing versus applicat executes real time whereas the former requires batch in the context dissertation focuses on all processes that are required to acquire support the fault process.

A clear distinction in the architectures of data acquisitions, requi [28]. Each of these categories has specific issues and need to be resolved sepa

overlap or dependencies exist. Another transformation to the collection and analysis re
is to include a storage, retention and access methods for data coll

The architecture patterns in Figure 9 are derived from the wide area monitoring
communication views in [2] and [28]. In Figure 9, there is a requirement for multip
communication links within and between substations. One of th
substation to the control centre link. The interface management and data mod
systems should conform to the standard 1970 second communication
between substations. Likely be a fault recorder communicating to ano
secure gateway appliance on the substation boundary.

Both of these communication links may exist over a wide area network. There is a need for fa
incoming and outgoing control centre links, with low data contenti
communications between a substation and control centre exists.

Figure 9 A substation information collection paths in the Wide Area Monitoring Sys
and fault event records capture [28]

Information collection paths in the figure can occur between Devi
Device 1A and Device 1C. Communication to and completely
Device 1C. Communication to and completely

have to support the same protocols. Similarly, Disturbance 1 will broadcas
information to DFR1. Substation 1 will communicate the disturba
centre. Within the control centre, internal communications can en
notified and event analysis performed to ensure that the fault does

Figure 10 Figure 9 create a fault information storage pattern.

Figure 10 A substation information storage pattern Wide Area Monitoring System
and fault event records capture [28]

In figure 10, the information storage pattern indicates that each device can store its ow
Data can be stored in a relational local as the Wide System design,
this can be both an advantage and a disadvantage. An advantage
effectively by smitting or requesting information to and from an ext
device processes. A disadvantage is that integration of this devic
tightly integrated devices processes.

Due to the distribute of the substations and control centres, it ma
clustered database environment to aid in reliability and performa
example of this would be the creation of a database that contain

device identifier or event data that would support analysis of rec
substation.

Figure 11 and figure 10 indicate the access methods for stored disturb

Figure 11 A substation information access paths in NIST Conceptual Reference
[1] and fault event records capture [28]

Figure 11 introduces access paths to the data that the requirements fo
domain communication paths indicated by the NIST [1]. Depending on the documentation
and knowledge of the device interfaces, access paths may or ma
directly. In the context, web client that has its deployment components
accessing information more efficiently. A peer-to-peer service
buses will aid in the routing of control and information to provide effective access to

The collection, storage and access architectures are the process of
performing fault. An detection method that uses two ends of the transmis
problem to which the collection, storage and access architecture
that the data has landed at a specific location after the occurred.

endefault location makes use of stamped events as in power relaying and control [3.4].

Reports by the NIST indicate that standards for [2] storage and acces

3.3.5 Architecture Alignment

The mapping of the models selected for the discussion does not expose itself to the changes that affect individual models information to be supplied to the nature of standards implementatio such that industry bodies may not necessarily dominate models due to the vast number of standards. It is important that all mode considered, however certain model mapping are already underway and th redefine any of these mapping efforts the best practise by instituted individual standards bodies where a model mapping is watchey exists do not exist.

Figure 12 indicates the scope of the model alignment.

Figure 12 The process and information requirement of TM Forum and standards

Infigure, the preferred nomenclature is indicated in 4 section 3.3.3 dissertation. Figure 12 indicates where mapping exists and where mappings process and utility information architecture. The mapping already exi namely the TM Forums, standards, the energy management and device mapping exists and drives a model to create the mapping between these s [35].

A mapping between the utility information architecture and the d
required.

A point of departure for model mapping is the Utility Information Architecture. Chapter 2, the Resource Trouble Management Model defined the processes that used to detect, analyse and report resource fault localisation analys [36]. A resource defined by a physical and logical components used to constru They are drawn from the application, computing and include for network elements, software, IT systems, [37]. The processes and compon information definitions form the basis of the mapping exercise.

Table 5 contains several definitions that will be used to align the information required. contains an extract from the IEC 61850 model was donated by ABB to th Workgroup [38].

Table 5 Selected IEC 61850 logical node groups [38]

Grou	Type	Logical N	Usage
P	Protection	PDIR	Decision to trip base surrounding faulted
R	Protection Relate	RFLO	Fault Location
I	Interfacing and Archiving	IARC, IH	Human/Computer Int
M	Metering and Mea	MMXU	Measurement
X	Switchgear	XCBR	Circuit Breaker
T	Equipment Transf	TCTR, TV	Voltage and Current

Figure 13 indicates a map between previously unmapped architecture entities found in the model definitions. By analysing the key model mapping between the utility information a device architecture is possible

Figure 13 A TM Forum and IEC model mapping diagram

Figure 13 indicates that gear equipment transformers are physical equipm and archiving data as application types. This defines the usage of these applications in computer interaction in substations. Computing is as capability enabled by a substation device. Trip decisions, fault location, metering a are data centric computing tests that generate information.

The mapping performed in this section provides a conceptual view information will be structured. It also provides a high-level view of the information transf information structuring requirements.

3.4 Service Oriented Architecture

The proliferation of system engineering methods and architecture aimed to resolve design flaws like tight coupling and low cohesion systems. Software engineering tends to produce software that is ea deliver and manage systems. The flaws in design are present most industry verticals, inc power utilities.

In order to integrate legacy systems, service-oriented architecture (SO proposed [39] [40]. Technology companies also note the usefulness of advanced metering [41]. A service-oriented architecture used for the same goals tha software engineer achieve, namely abstraction and component deco

An SOA views a system as set of components, known as
specific piece of functionality. Functionality delivered by these
provide some type of technical a
service in design to maintain design consistency
services framework. References a smart grid reference
reference architecture an SOA reference model
pattern. The NIST reference framework
several providers of information across the
on page 4 and page 7 the JBOSS reference architecture
composition layer consumer layer
interchange and web interfaces
orchestration in the middle layer of the service architecture
14 is therefore representative of the service layers used in this di

The reference list used in indicating its architecture
references every major software vendor in the software-based
architectures some form or other. For example Microsoft, IBM, Oracle all
frameworks that conform to a layered service architecture pattern. S
layers of a framework may follow a pattern indicated in

Figure 14 A layered service architecture. Source: Smart grid reference framework
middleware reference architecture and an SOA reference model

The general pattern is that specific layers indicate the context o
service. Service descriptions tend to deliver these classifications [43]. Mediation of control
and messages though an enterprise service bus (ESB) is one type of mediation platform
an SOA

At times, later information requirements are not fulfilled due to increased response
caused by an increase in the number of handover and transformat
architecture. This occurs when services are very granular and
Granularity of services balances reusability and performance [43].

Most development languages and systems enabled to deliver an S
However, delivery of services via web services has been the most pr
means of smarter information system deployment, management and
services are a current reality. Advancements in systems engineering offer existing
methods by increasing the coverage of the artefacts that the cu
deliver. For example, the Unified Modelling Language (UML) delivers concepts like abstra
encapsulation and polymorphism [51]. Since orientated architecture uses business proc
aggregate and decompose processes into web services implementation. Service-oriented
architecture also encapsulates functions and information structure
the case of-based services, a single service with multiple methods
form of polymorphism. In the scope of this dissertation, the SOA
classification approach to deliver functional multiple service units

Composite applications consist of one or many web services [43]. These composite
applications serve a specific purpose of web services or physical u
aid in delivering a piece of functionality. The activities indicated
coarse-grained services. This study opts for fine grained in order to i
the fault information access pattern discussed in Figure 1.

SOA offers a mesh structure operations and provides the necessary
operations. The IEC standards to deliver open systems architecture f
substation systems integration efforts.

3.4.1 Services

Services are functional components that have defined inputs and outp
application information or they can be used to create a standard
common information model. Services can be fine grained which m
have a few special methods or operations that delivers a very specific

service can be coarse grained which means that the service can d
of the same or similar functional requirement [43]. This is termed servi

Figure 15 indicates a simple web service implementation.

Figure 15 A simple web service application interfacing with service

As indicated in Figure 15, providers supply interfaces. These are the best
that form part of the standard implementation for the device and
device interfaces may write data to a file system or to a set of da
be in a standard format like the multiple information architecture [24]. CORMTRAS [24]. File writes
can occur as automated file downloads or to a common information
platform. The services that use data from Data Services are ator
units that provide data without any context. For that uses the data
capability of device or device firmware indicates a capability
access and manipulation [51]. These services expose primitive values lik
values. In information services, semantic context to data and
information service is needed to that of the information processing service
in [39]. It is proposed that sources are wrapped into a framework, lik
Resource Framework, that provides the necessary reliability [39]. The for th
Web Services Resource Framework (WSRF) provides the capability
test if an information resource has undergone any changes in sta
data store value has changed, the WSRF, it would a application further
mentioned that the control of data architecture design application. The design

used in the fault detection architecture that is discriminated proportionally closest to the information needed in the service function. Figure 16 indicates the scope and domain for either service classification.

Figure 16 Fault detection information and data service Data Providing and Information Processing Service [39]

The consumer and composition layers of the architecture work for the architecture that data processed from information and perform the actual processing for the data to Web Services Description Language (WSDL) specifies the functions required for Information services. A WSDL contains the interface names, messages st protocol identifiers that form part of a service. Extensible Mark up Language (XML) [44] A WSDL implementation document schema. A fault information service can be i or multiple WSDL documents depending on the availability of data

3.4.2 Mediation

A service bus is an application that mediates communication [45] in a s a service oriented architecture, transform, and route a service bus, transform, and route messages. It therefore serves as a key software application in integration environ like machine core and memory processing are standard requiremen for any enterprise grade software application. Mediation include the ability to federate buses, message handling and message gro metrics to define the ability of an ESB to fit in metrics are chased [45] The metrics are chased

- The ability of the service bus to interoperate with technologie
- The ability of the service bus to be extended by increasing allowing machines to operate in a clustered environment;
- The ability of the service to deliver secure and reliable messa
- The extent of familiarity with the ESB application interface; a
- The availability and failure recovery of a service bus

In this dissertation is assumed that the service bus infrastructure will house th current for and testing the application of an unspecific infrastructure for this dissertation

3.4.3 Schemas

Data schemas provide a structured view of the enabled service environment. Schemas contain element, data types and rules. Extensible Markup Language (XML) document having Extensible Markup Language (XML) file extension. Element XML document structure can appear as single elements element that are grouped by a context in XML document. These are simple and complex types respectively. Schemas provide much needed flexibil design.

Modelling tools like IBM Rational Software Architect provide a functional schemas as UML class models and XML Schemas can directly from the UML. This is presenta useful as you can leverage off the UML modelling capabilities like aggregation.

3.4.4 Processes

Processes are defined activities that specify objective [4,6]

A process executes in a specific order and generates information outputs. An opportunity therefore exists to create functional components and application architecture. The Business Process Modelling Notation (BPMN) [4,7] and Business Process Execution Language (BPEL) [4,8] support the composition and ordering of process activi Each process step contains a series of pre and post conditions, t that describes the purpose that the activity fulfills on the overall system processes [4,0]

Figure 17 indicates key BPMN components in process flow.

Figure 17 Basic business process modeling (BPMN) components. Source [47]

Figure 17 indicates that process activities are ordered. Arrows in the connections between process activities are defined as part and e Process activities can have single or multiple process requirements accepts inputs from Process and Process Activity component in the pr controls the process flow. Process activities decompose granular structures that are more granular [43]. Control within granular activities can execute using BPEL variable assignment, error throw and fault handling constructs as can be implemented [48]. Less granular control can be accomplished Typically, BPMN rides the activity level flows, whereas BPEL rides the level web service control.

Business process notation and execution language are significa service-oriented architecture. They support the ability to build applications that a function le higher than that of known application. Service is ongoing for application su personnel in the application process. It is important to model the corre hierarchies to resource process engineering and measurement at the corre

Figures 18 show the processes relate back to the total process cove of Chapter 2. Additional process groupings in the ITU are not shown in these processes. Resource Performance Management Data Collection and Processing

Figure 18 presents the level 1 and level 2 processes grouping within the context of the la framework.

Figure 18 A defined process hierarchy that supports fault event rep Management & Operations Processes [36] and AMDOCS [13] Source: Resource Composition

Figure 18 indicates two process levels. Process levels 1 and 2 are stand adopted by the TM Forum. In this dissertation there defines the process definitions advantage of using the selected process from the TM Forum. The Forum hierarchy places no constraints on the order in which the process activities execute. The process activities the order in which the process should be best suit in the operations policies. Figure 19 provides an example of an Management & Operations process by combining the notation from the process from figure 17 activities in figure 18.

Figure 19 An end-to-end Resource Management Operations process modelled in BPMN

Figure 19 contains the process flow modelling in BPMN. The process pattern indicated figure is reusable, thus it can also be used as a composite application. This provides automatic reuse of the process definition. A process definition is a service hot vector using in figure 19. The decomposition of the process is developed to deliver the fault detection services. This additional decomposition will break down the indicated in the figure, and lower.

3.4.5 Integration Overview

In order to achieve suitable levels of a integration, a distribution of the integration functions and information [3]. The use of patterns forms this integration as these patterns solve recurring problems [5]. By their nature, patterns support the dev modular and reusable components. For example, a decoupling pa decoupling of the logic and presentation [5]. Compounds, the flatter ely architectured in figure 14 pattern for integrating service consumers an by abstracting each of the layers. The way from a figure 14 provides the necessary abstraction but may pose a problem in the number of ft consumer to target is one. The service call pattern and management allow for low control and information. Research shows that protection rec second response [2] times

Integrating data also make use of data integration pattern may result in of decent data or cent rabi based on functional and performance

requirements. The substation integration is the creation of functiona
placement of the existing device functions into the appropriate
substation systems hierarchy. The extraction of the existing function
decouples the function and places it into the boundary where the
requirement this could be done either physically or logically. One
functions form a unit that accepts instrumentation inputs and pr
device functions.

The grouping of functions is seen in the design of an IEC 61850 c
station, bus or process layer is a function [2]. Figure 2 is a spec

3.5 Network Topology

A network is as a series of connected computers, systems or devic [1].

Notwithstanding the issues relating to fault infrastructure, researc
technologies as vital in the interconnection of substations and
Activities in the area of network standardized in the interest
initiative. Network research outlines key requirements, such as int
accessibility, area and area network. Figure 2 is derived from a
reference model used by the NIST [1]. The figure indicates the connection types
between control centres and substations. Then, however, the NIST
indicates the connection to the field networks and in turn to substations.
consumer s request for information may need to traverse multip
information frequency and latency is a consideration in the applica

A recommendation provided earlier is to place well to the function
the data to ensure less overhead and contention.

Figure 20 Substation network connectivity requirements for new detec
and Roadmap for Smart Grid Interoperability Standard Reference Diagram [

Figure 21 is derived from a known substation architecture that repres
[25]. The figure indicates a faster communication for the electrical equipmen
to relay and metering devices at Gigabit second. Substation communication
enabled through Gigabit Ethernet switches that connect to the substatio
Station bus enable substation communications over wide area ne
represents the substation communication subset of the smart grid
NIST in figure 20.

The need for fast processing and application placement and deploy
application on this. The processing application of Figure 21 would require a
more robust network as this has an immediate impact on safety an
post event analysis is not as demanding as real time action required for

Figure 2.1 Communication requirements for a 61850 Architecture [2 detect. Source 61850 5]

Networks are required to support multiple categories of data namely o operational and control [49]. The network scoped for this dissertation supports mult however, the operational and data is used specifically as sources of c detection. Control information is information sent by an operator to i substation.

Recommendations in the report by the IEEE indicate that the Ethernet channels are more deliver protection based functions in a substation environment. The recom and disadvantages of both serial and IP based communication r maintenance and scale characteristics that can be used to measure c [49].

3.6 Conclusion

This chapter with the information wide area monitoring of the s detailed specific information requirements for Device information will grow due to increased functionality and vendor interest in the areas chapter also discussed the trustee setting to effectively cement and access of integ substation data. A simple data store is proposed to be extended to cater for multiple device inputs within the same substation.

The chapter further discusses a common mapping of process and information arc service classification. A generic SOA reference model is derived from industry and vendor models. The reference model is positioned as providers of data, which is information in the upper layers of the reference architecture. T presented to provide context to the implementation requirements Services, data structures and description languages are the exclo deployment units in an SOA.

The chapter finishes with a future view of communications. Intelligent communication in power networks [50]. An increase in the volume of data means tha need to react by developing standards for management and analy real time using existing network topologies and technologies. Th infrastructure can only be successful if the communication network co delivery of reliable and secure fast and accurate information exchan

CHAPTER 4
UA ANALYSIS AND DESIGN

4.1 Introduction

The previous chapters of this dissertation motivate for the use of
and information access methods with solution based delivered. This
chapter focuses on the analysis, design and implementation withi
architecture constraints. The delivery of the required artefacts and deployment u
dissertation is on the Unified Approach (UA) as a guiding framework

In software engineering, an object-oriented lifecycle uses a requ
approach to model and [5]. The Unified Modelling Language (UML)
view that software is modular in design and implementation. A subset of
of UML artefacts for the delivery of analysis. These are:

- Actor identification;
- Business process;
- Use cases; and
- Sequence diagrams.

4.2 Wide Area Architecture Concepts

The system architecture concepts used in this dissertation abstract
of the system into a rich software storyboard that contains one
information and control flows. The subsequent sections of this ch
view is decomposed into the components and physical topology tha
in the proposed layered target architecture. Each interaction pro
contextual and classified as information used within one of the core po
transmission or distribution processes. Within the power network system of systems
indicated [1], a decomposition approach is applied to specific nodes on the network s
interconnecting nodes, like bulk transmission substations. Rese
equipment is amongst the most important [3] [2]. These devices are:

- Digital Protection Relay which are used send trip execution signals to o
- Circuit Breaker Monitor used to monitor breaker signals, and
- Digital Fault Recorders which record station wide information, and
- Substation machine computer interfaces that access devices
to the substation network.

These components with unique hardware and service application interfaces
common protocols via bus and with other substations via a station b

Figure 2.2 gives context to the control and information flows indicated
Research in the areas of bulk data storage, classification, and access
[2].

Figure 2.2 Substation device components for distributed information Source: Concerns and decentralised collection for Wide Area Monitoring Systems [2]

The figure indicates that the distribution of structures is a series of substations and Data Stores (LDS) that gather data from Merging Units collection process to a Central Data Store (CDS). The essential function of an and CDS is to collect data [2][4][7][9][5][4]. A MU is a physical devic unit that accepts binary and analogue inputs from the MU [5]. The devic serves as a mediation device that transforms and aggregates Transformed information can be loaded via real time batch or real An LDS is a local store that serves the substation's protection, control and requirements. Information propagates to a store that serves operational and requirements for other areas of the network, in a tree or ring, as a pattern for serving different functional groups [2][8]

4.3 System Domain

Figure 23 expands on the component architecture presented in Figure 22 and addresses the architecture concepts and creates the next level of detail for the dissertation system. A domain provides the necessary overview of the system interacting components.

Figure 23 A system domain diagram for a wide area system based on centralised and decentralised data requirements

Figure 23 indicates the following relationships:

1. Power System Generation, Transmission and Distribution domains that are independent of, but are related under a wide area monitoring environment;
2. Power System Generation, Transmission and Distribution domains related specifically to PS Generation, Transmission and Distribution environments;
3. Substation nodes are either generating, transmitting or distributing;
4. Power System nodes (PSs) have equipment. For example, a substation physical control devices.

5. Merging Units are physical devices.
6. Data Stores are special physical devices
7. Local Data Stores and Central Data Stores are special Data Stores

4.4 Protection Use Case Actors

Figure 24 contains a view of the actors that interact with protection analysis and operation. Natural pathways (actions) may be performed by the role of an analyst

Figure 24 Power system use case actors for protection

- Operator: This person is the control centre operator that has the a the stations connected to a control centre or transmission subst
- Analyst: This person analyses available information in order to produce st using faulted line information.
- Intelligent Electronic Device: This device is a device that enables automated analysis an control functions.
- Data Concentrator: This is a system that acts as a store of information and data

The business process in 4.5 outlines the requirements for generating data. It assumes that a disturbance occurs within the substation. The human actors tha interact with the system are not involved in the physical resto disturbance. A technician manages the process in the data trouble tickets raised for resolution. Human actors use the data and information access post fault events.

4.5 Fault Detection Process

Research suggests that a fault analysis sequence uses three pro
faulted line. These are Fault Detection, Fault Classification and Location. A series of
activities and decisions extracted from the fault transmission line fault analy
readings from both ends of the fault line. The Business Process Modelling Notati
used to translate extraction into an implementation view. The fault
process does not include the actual fault classification or locatio
focus is on making detected fault data and conforms that available at
perform the fault classification and location. This is the ability to
decouple functions and provide information to other consuming p
indicates the business process shows the contract of the figure outlines require
process inputs, process outputs and the activity processed on row
indicate the data inputs needed. The each process line indicates
the process output. The double dotted dashed line indicates process contro

Figure 25 A business process for detecting a fault (Line 53)

Source: Dequatiqbine [53]

The fault detection process used for this dissertation performs the following fu

1. Uses line readings to calculate a current vector;
2. uses line readings to calculate a voltage vector;
3. compares calculated vector values; and
4. sets the appropriate vector values.

The process diagram 25 implements the fault detection equations indicated in table 6.

Table 6 The implementation process activities for fault detection equations. Source D Equations (1) to (5) [53]

Processing Ay	Fault Detection Equation	Equation
getCurrentV	$\delta D(t) = I_S(t) + I_R(t)$	1
getVoltageV	$\delta D(t) = V_S(t) - V_R(t) + lR[I_R(t) + L(dI_R(t)/dt)]$	2
checkZeroV	$\delta D(t) = 0$	3
checkZeroV	$\delta D(t) = 0$	4
compareVe	$\delta D(t) = I_F(t)$	5

The following legend contains the definitions applicable to the fault detection equat referenced in table 6 [53]

1. $V_S(t)$, $V_R(t)$ - Vectors of Phase Voltages at line ends S and R respectively
2. $I_S(t)$, $I_R(t)$, $I_F(t)$ - Vectors of Phase Currents at line ends S, R, and F respectively
3. l Length of transmission line
4. R, L Self and Mutual line parameters

It should be noted that mechanisms to determine equipment condit rules that must be stipulated. For example, the creation of defined using known isolation constraints should be used in the fault anal logic to determine the fault isolation. The exclusion constraint is stipulate beforehand for security, personnel safety and in protection scheme

4.6 Fault Detection Use Cases

The use cases figured not indicate a specific implementation tech
that some device or system will fulfil certain functions. For exa
initiated by a electronic device that generates data. The use cases focus on
the data produced and how to create a physical user with a view of
boundary, for the purposes of initiating fault detection.

Figure 26 A fault detection use case diagram

The diagrammatic representation provides a clarity of how the analysis process will be
and which actor will be engaging in the process. The requirements in 4.5 a basis for t
use case diagram and the scope of the analysis sequence and the comp
additional use cases that allow operators and analysts a means to access info
These are updating information and creating new analysis data from da
store or concentrator. A diagrammatic representation is an importa
functional and boundary of the system. A textual view of the use cases
information for the detection process. This is a description of the use
case in order to map the use cases for the work. Table 7 contains additional
use attributes.

Table 7. A set of actual use case descriptions for the fault detection process

Use Cas	Use Case Name
UC001	Generate Current Entry
Descripti	This use case describes the automated process initia data for analysis purposes.
Actors	Intelligent Electronic Device
Triggers	Sampling frequency checkpoint is encountered
Pre Cond	No event record exists
Post Con	A device generates a recording current values
UC002	Generate Voltage Entry
Descripti	This use case describes the automated process initia data for analysis purposes.
Actors	Intelligent Electronic Device
Triggers	Sampling frequency checkpoint is encountered
Pre Cond	No event record exists
Post Con	An automated event record, holding line voltage valu
UC003	Calculate Vector
Descripti	This use case describes the fault analysis vector cal
Actors	Intelligent Electronic Device
Triggers	A disturbance is encountered in the substation
Pre Cond	Continuous vector calculation
Post Con	Vector value available for use
UC004	Calculate Current Vector
Descripti	This use case describes the calculation of the current ends
Actors	Intelligent Electronic Device
Triggers	A disturbance is encountered in the substation
Pre Cond	Continuous vector calculation
Post Con	Vector value available for use
UC005	Calculate Voltage Vector
Descripti	This use case describes the calculation of the voltag ends, as well as actual line parameters.
Actors	Intelligent Electronic Device
Triggers	A disturbance is encountered in the substation
Pre Conditi	Continuous Vector Calculation
Post Con	Vector value available for use
UC006	Update Vector
Descripti	This use case describes the updating of the calculate
Actors	Intelligent Electronic Device, Data Storage Concentrator
Triggers	An alarm is processed
Pre Cond	No vector value available for update
Post Con	Vector value updated on Data Storage Concentrator
UC007	Compare Vector

Descripti	This use case describes the process of comparing the
Actors	Operator, Data Concentrator
Triggers	An alarm is raised and notifies the operator
Pre Cond	Polling yields no change in event directory content
Post Con	New record added to the event directory
UC008	Update Information
Descripti	This use case describes the update of generated info
Actors	Analyst, Operator, Data Concentrator
Triggers	Notification of an event change is produced
Pre Cond	Normal operating conditions encountered in the subst
Post Condit	Abnormal operating conditions encountered in the sub
UC009	Create Analysis
Descripti	The use case describes the process of running an ana
Actors	Analyst
Triggers	Notify of a validated user
Pre Conditi	Analysis result not available
Post Con	Analysis completed and results updated

4.7 Interaction

The use case diagram and use case are used to define interaction process. Figure 27 presents this interaction requirement as Telecom sequence diagram. The swim lanes in the figure delineate specific use case interactions.

Figure 27 A sequence diagram for the interaction

Each use case contains the required control flows that advance th
next. The use cases contain the flows that implement the pre and
The sequence diagram indicates the interaction between control flows r
analyse the detected provide a more detailed view of the interac
framework classifies interactions. Figures 28 and 29 define service framework in
figure 14 in Chapter 3. The service framework layers following definitions:

Figure 28 Service classification definitions by service layer for interactions. Source Figure 14.

- The Consumer Layer: This layer provides a machine interfaces to consume composite applications or processes from the lower service laye
- The COA Layer: This layer composes atomic services, composite applications, atomic services to connects to interfaces, synchronous data [54] into information for consumption by the higher layers. This l warehouse update and retrieval operations. Are indicating principle applied to substantial integration problems. Would be a capable-of-real processing or for batch processing. Latency and performance needed to fulfil ba reporting requirements are or batch processed warehouse require
- The Provider Layer: This layer exposes native device or application inte
- The MSPCS Layer: This layer is an operations management layer from control signals and also security. Data management is layer

also termed as situational awareness data. This layer produ
sensitive information that is termed as situational awareness [30].

- The CM Layer: This layer enables configuration management. This co
61850 Part 6: Substation Configuration Language (SCL) interfaces and message
structures. SCL is an XML based configuration language that contai
specification elements [21].

Components identified in the interaction sequence, based on the
service framework to derive the diagram indicated in figure 29 in the interaction
pattern uses the analysis case (UC009) as an example of how the service
interaction is defined.

Figure 29 A recommended interaction for Use Case 009 mapped to framework
layers

In figure 29, the analyst and operator are classified into the consume layer of
This is correct as the point of entry for analysts or operators are

substation or distributed to the indicated access given in figure 1.1 chapter 3

When the analyst or operator requests, the consume service in process component that may dictate the request requires a complex. If this is not the case, the process will initiate a call to the inform information service could require the federation of distributed de information services, it would simply call the data service that information configuration device database or the devices file system service to query the data returned from an analyst or operator re the intermediate layer service framework for subsequent consumpt services.

4.8 Service Modelling

4.8.1 Process

In this dissertation, the method of modelling a service starts with service aims to model. This is used a top down or bottom approach. The approaches are defined as

- Top Down: The approach uses a process view to classify the requir new service architecture needs to fulfil.
- Bottom: The bottom up approach ensures that specific data e classified first. This is a pull information - COMTRA-DE format as an entry point to coverage and availability of services. Upon to relate the bottom up approach to the required services information architecture information is required.
- Hybrid Approach: Both process coverage and implementation functions means that the functional requirements must be known.

In this dissertation, the definition accepted by the International Telecommunications Un aligned to system actions in 2-4 effectively means that devices and concent Resources. This conforms to the domain view given in this chapter which indicate that an IED and a data concentrator are a physical device th technology component, turn a type of Resource. The definition of the Resource definition does not indicate a service in the context of this disser dissertation service, defined in section 4.3.

Figure 30 creates a more detailed view of the 18 figure. The process followed for modelling of services uses distinct requirement decomposition, with finer grained requirements that lead to the delivery of service functions. Level 3 process groups are shown using the 30 figure. Definitions a lower level of decomposition than that found in [36]

Figure 30 Resource Trouble Management decomposition. Resource Trouble Management decomposition processes [36]

Figure 30 indicates that each level 2 process group has multiple level 3 p the level 3 process groups are grouped by one level 2 process hierarchy. This n define strict functional areas without creating a number of service functions. Decomposing complex granularity of functions, composite service applications, level 3 can be structured as a series

The definitions of the 78 page of the ITU process decomposition. Its indicat detection process touches a large process [36]. The table below indicate corporate definitions published by the TM Forum and ITU.

Table 8 Master process definitions from the ITU detection Source Resource Trouble Management (RM&O A) [36]

Level	Name	Original ITU Document ID
2	Resource Trouble Manager	1.A.3.3
Resource Trouble Management processes for the management o specific resources. The objectives of these processes are t resource trouble, isolate the root cause and act to resolve th Context in this dissertation This process group deals with the management, isolation and		
Level	Name	Original ITU Document ID
3	Survey and Analyse Resource Tro	1.A.3.3.1
The objective of the Survey and Analyse Trouble processes is to mo notifications and manage resource-alarm event records in rea Context in this dissertation This process group deals with the monitoring and management		
Level	Name	Original ITU Document ID
3	Locale Resource Trouble	1.A.3.3.2
The objective of the Locale Resource Trouble processes is to identif resource trouble. Context in this dissertation This process group deals with the analysis of data in order to locate		
Level	Name	Original ITU Document ID
3	Correct and Resolve Reso	1.A.3.3.3
The objective of the Correct and Resolve Resource Trouble re that have failed as efficiently as possible. Context in this dissertation This process group deals with the initiation of actions requir		
Level	Name	Original ITU Document ID
3	Track and Manage Resource Troub	1.A.3.3.4
The objective of the Track and Manage Resource Trouble i activities are assigned, coordinated and tracked efficiently, any open resource trouble reports in jeopardy. Context in this dissertation This process group deals with the monitoring and managemen		
Level	Name	Original ITU Document ID
3	Report Resource Trouble	1.A.3.3.5
The objective of the Report Resource Trouble processes is		

reports, provide notifications of any changes and provide ma Context in this dissertation This process group deals with the reporting of fault conditions to grid stakeholder		
Level	Name	Original ITU Document ID
3	Close Resource Trouble R	1.A.3.3.6
The objective of the Close Resource Trouble Report process the resource trouble has been Context in this dissertation This process group deals with the closing of fault trouble rep		

The table contains the following labels used to identify specific These are:

- The Level of the process Definition. The Utility Process Architecture TOM contains standard process definitions from level three and sometimes up to lev four. Where a defined process does not exist at the level, four five and beyond are indicative of the utility's own operational p
- The Name of the process defines the classification within whic activities can exist
- The Original ITU Document ID indicates the process relative to the [36]; ITU
- A short description of the scope and of the process grouping
- Context in this dissertation provides the description of how the process for this dissertation.

The definitions included in the table are small percentage of the the process architecture. A full view of the process work is published on the in by vendors like AMDOCS [1]. However without visibility of the process defi document is rarely useful. For purposes its [36] can be used as cross-reference.

Process classifications do not necessarily indicate a sequential fl sequence requires. The document IDs included in the ITU process document represent an initial sequence requirements, considered by the Original Doc ID in table 8 to indicate an implementation view of a service framework.

Figure 31 A business process sequence by UTU process referring to unique service identifiers

A single text identifier is proposed with the implementation of the fault detection service. The text boxes on the lower end of the red dashed vertical line figure 31 are the constructs represented by the text boxes at the end of the red composite applications.

Figures 32 and 33 show that the process can be executed in some sequence based service modeling development. The figure shows a flow of all activities attached to level 2 Resource Management Management processes.

Figure 32 A level 2 BPMN process model for Trouble Management Service including trouble activities

Under circumstances where process reuse is more frequent, the incorrect design of service granularity may yield services that are not reusable and a number of service operations added to an incorrectly levelled service

In order to complete the service model, the process of detecting a faulted line using fault calculation is used. The use cases delivered to the original fault detection process is from 25

Figure 3.3 A requirements map the detection and process requirements

All but two use cases map to the original requirement in 2.5 Tbc additional Use Cases, UC008 and UC009 are included and that the inclusion of the fault de and its associated results are clearly articulated

Figure 3.4 and Figure 3.3 indicating the process inputs required to support each use case. The figure shows that a possible 8 processes from the Resour Substation - Device Management process grouping are required for process. These are;

1. Monitor Alarm
2. Monitor Sits
3. Identify Root Cause
4. Close Report

Figure 34 Mapping fault detection level 3 activities at the Resource Trouble Management level 2 process

Figure 34 displays the information and process flows. The process has the follow characteristics:

1. The Monitor Alarm activity (1.A.3.3.1) accepts inputs in the voltage values (UC001 and UC002),
2. A decision point occurs if a disturbance has been encountere
   either
   a. monitor the status disturbance (1.A.3.3.5) in turn update data s
      information of the monitored event, (UC008)
   b. or continue with a root cause identification (1.A.3.3.2),
3. Current and voltage vectors are calculated (UC004) and used as inputs in
   root cause analysis process activity(1.A.3.3.2),
4. The root cause process activity (1.A.3.3.2) updates
   a. vector information in the substation data store (UC006),
   b. updates other supporting information (UC008) and
   c. creates analysis outputs (UC009).

The vector compare activity (UC007) receives the calculated output current and (UC004 and UC005). The vector compare activity (UC007) provides input to the MonitorStatus activity (1.A.3.3.5),

5. After the cause is identified (1.A.3.3.2), the AssignCoordinate is ignored and the process flow is directed to the MonitorSta event that no device equipment needs replacing, and
6. MonitorStatus (1.A.3.3.5) is the final process flow to the Close (1.A.3.3.6). Both of these activities update the substation c CloseReport (1.A.3.3.6) terminates or ends the process.

The process flow represented in Figure 34 is a manual through to the implementation of services. An additional step will be to logically group use cases that h single unit with multiple methods. This is possible for UC001 and UC002. This is not possible for UC001 and UC002. Functions required in th use case may not exist on the same physical device. The application may need to consider the impact of creating a single method to multiple ser multiple methods with single methods. The performance overhead and number of ser number of services increases.

Up to this point of the dissertation, all required building blocks to suppo reusable components are in place. The UML interface set produced creates from the design requirement, or business process, through to the sequences that next section deals with the deployment architecture.

4.9 Service Deployment

This section deals with the deployment of the classified ploymen of the service framewo Figure 35 outlines the placement of the service work in the framework indicated in Figure 14 Chapter 3. Figure 35 indicates the split of provider and consumer use case are use case 001 to use case 006. These are native application functions lik calculating vector values. The consumer use case 007 is a human-machine interface of the consumer use case 009. The default data entry form deployed on the service infrastructure. This may be in a web-enabled form. The advantage of web services that the forms in both thick or web client deriva web service.

In figure 35, a operation monitoring process is an alternative process flow

1. The provider services use case 001, and 002
2. The operator compares the vector output in the human web s forms that implements 007

3. The operator updates information about the substation statu through the computer interface via web services forms, that impl
4. The operator updates status of the substation through the human computer interface via web services forms, that implements
5. An optional step is the creation of an analysis of substation data The analysis can be created by a manually filling web service forms that implements An optional step will be an update of the store using the web service forms that implements

Figure 3.5 The fault detection employment message exchange

The figure provides the opportunity to extend the process by incr A new requirement will translate into a use case that traces through if the utility deems it necessary to include a work order for a technician the service model would only change by enabling the requirement classifier process step, 1.A.3.3.4 Assign Coordinator. Figure 3.6 indicates a new use ca called Assign technician.

Figure 3.6 Assign a new use by reasoning an inactive in the fault detection proce

Figure 3.7 extends the previous deployment model by including the assignment of a technician to directly identification of the assignment of a technician to the human-computer interface service forms that implement the 1.0 0

Figure 3.7 The fault detection service deployment and message exchang assignment

Figure 3.8 changes the order of the fault detection activities. The assignment of the technic takes place before the first decision point. This purely process step occurred after th identification step. One reason for changing the order may be to technician once the initial process starts. A point to note is that the order in which the process executes. This means that the BPM compiled and deployed onto the mediation layer. No changes will be made to th structure unless the change of the text boxes, or drop down status placed on the data entry form. This type of change will require an data structure.

Figure 3.8 show that the process step keeps its original process after the monitor alarm step and before the first decision point in the proce

Figure 3.8 A reordered fault detection process indicating a change to the technici process activity

The final section of this chapter shows a version of the implemented model perspective. The model is developed in BPMN using an open source business proce Bonita Open Source BPM [5.6]. The specific data entry page is included for a single process. The data entry page uses inputs from the AnalogChannel ent model [2.2].

Figure 39 indicates the BPM Tool specific implementation of the fault detec

Figure 39 shows tool specific deployment of the figure. The figure indicates that process is not complex, complexity can be built into the using the available components on the tools of the Monitor Status process. Monitor Status process contains the appropriate web service connecto connector icon in the top right corner of the Monitor Status proces links the web service call to the data entry page. Figure 40 indicates the data entry page co the process activity via web service. Once the process executes, user s web browser so that the user is able to update data in the

The project developed in the BPM tool is exported as a Java archiv server. This again supports the ability to have a composite applic deployed to multiple applications. Across the power system infrastructure this is useful is for management and deployment strategy in Chapter 3

Figure 4.0 The data entry page of the Manage status activity

4.1 Conclusion

This chapter focuses on the analysis and design as a fault of the service process. The fault detection business process provides the delivery of the artefacts in line requirements. The artefacts evolve the requirement from a business process specification that can be implemented. This implements the ability to frame the final design unambiguously.

The chapter plans specific set of process activities to a defined process process enables structuring of components composite or atomic ability to deploy the process in a service by business process provides flexibility the implementation and managing atomic functional units. The reference framework for processes, together with the requirements to ensure the linking of service units to their classification. An implementation viewpoint change some of atomic units by creating units coarse

This chapter proves the facility of a service consumers and providers, and processes activities composed in the composition layer of the referen provides flexibility in ordering and calling services out of the busine also decouples the deployment of specific services and reassociated application. The chapter closes using the BPM process to display a data entry page for updating data in CoMTaRA DE Single activity

CHAPTER 5
CONCLUSION

The final chapter interprets the design approach used in the previous ch this dissertation. The chapter also proposes future research areas.

5.1 Closing Remarks

Availability of correct information at the right time has become a challeng encounter many obstacles when trying to source data, frequency me and quality of data are always a problem. The application of this dissert provides a clearer view of the collection, storage and access me service deployment models used in this dissertation. This is a flexible means for chan requirements and adapting to the procedures for changing from lega architectures to a functional approach. Now requirements are implemented using new architectures to reach the scope of dependency on standard legacy systems.

Standardisation is part of an organisational change process that organisation into a different direction. A strategy that is built on transparency in operations if the organisation aims to attract motion architectures in subst important and vital for expansion and integration of technologie information exchange or as the wave of electronic devices grows becomes more accessible. The exchange of this information, moisture, which requires high levels of quality, reliability and time balance betwee formation. This dissertation proposes an approach that exposes information that is context be used by the necessary persons or systems without being co architectu

A model driven approach to the design of substation architecture will t however are needed to safeguard from creating legacy that is not fit for the future. The fault detection process is many processes that offer accurate expos information to stakeholders on the state of the power system. Consider which events exposed as the volume of information can become overwhelming. A correc notification interface to consumers and other utility personnel service architecture to ensure maximum agility.

With the explosion of information and industry trying to find more new wave of engineers, skills of renewable energy, telecommunic

engineering are required to move the energy industry into a direction th
how energy assets can be managed and protect

5.2 Future Work

The problems encountered with substation integration data that more holistic in
requirements are placed on data. Data quality focuses on the reli
database, or transported within a Further work is required to detect and
deliver standards that support collection, storage and access of dat

Standards support the creation of applications for design integration ac
between previously unrelated information. The TM Forum, IEC and IEEE
standards inform development of applications that play in both energy
sectors. As more systems are required to integrate, a wider variety of t
challenge industry vertical models. Future work will focus on using
establishing process framework in energy and telecommunications. Process
architectures not only ignoring efforts but also strong smart gr
analytics. Currently no analytics standards [2]. The aim should be to
harmonise a message exchange level than entity definitions to generate
transformations based on XML to create consistent and reusable

The information needed for wide area monitoring of power systems sho
modelling and placement of data to meet the needs of specific inf
information providers. The IEDs that there is a need to certify the data
operational purposes. Purpose effective control checks results in delivered
data. The NIST indicate that distributed cluster processed environme
Apache HADOOP is a possibility [2]

Software engineering is an important mechanism in the delivery
discipline will continue to grow and evolve constantly changing
the software delivery process. The implementation of key objectives challen
updated to reflect more effective and efficient design in form of sy
analysis deployment and traceability requirements. This increases the conf
delivered to meet the future work in this area will allow forward an
code generation for processes system that will further support model
architecture and design.

In order to move data efficiency across networks to support reliability
redundant information requirements. IEDs delivered over public a
private work infrastructures are vital for management. The area of substatio
information integration focuses on the creation of collection, pat

storage and access. The measurement of the effectiveness of the implements that this dissertation is a key area of future activity must be in the study of methods for collection, storage and access of power systems.

Cybersecurity, although not covered in this dissertation, is another area that offers a possibility. With the volumes of information and untapped analysis for information exchange are the analysis of patterns provided to exploit vulnerabilities in the power grid. The power grid control resource, and will grow due to an increase in exposure at key interconnection points.

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Appendix A Prosecoverage map indicating classification for Sarwit Resource AMDOCS Online Posters [13]

Appendix B: BPM representation of fault detection services

A Source Detection equations (1) to (5) [53]

BPM Proce Activity	Fault Detection Equat	Equation
getCurrentV	$\delta D(t) = I_S(t) + I_R(t)$	1
getVoltageV	$\delta D(t) = V_S(t) - V_R(t) + R\,I_R[t] + L\,(d\,I_R(t)/dt)]$	2
checkZeroV	$\delta D(t) = \delta D(t) = 0$	3, 4
compareVe	$\delta D(t) = I_F(t)$	5

Variable Description
VS(t), V-R(t) Vectors of Phase Voltages at line end
IS(t), IR(t-), IF(t) Vectors of Phase Currents at lin respectively
l Length of transmission line
R, L Self and Mutual line paramete

Appendix C: Resource Resource Trouble Management decomposition into levels 3[36]

Appendix D Standard Bezmaud detection process level 1 to level 3 process

Appendix E Detection cases derived from equations integrated standardized BPM fault detection

Appendix F Physical deployment view of the BPM process on a service reference arch
use cases