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Title	**Control Platform Specification Summary**
Synopsis	This document outlines the requirements and functionality of the controller platform. The document also contains an overview of the chosen hardware and the platform's software architecture. The workflow used for the development of the control application in the form of application functional blocks (AFBs) from Simulink model to Programmable Logic Control program running within the virtual machine, is also outlined.
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Technical Acronyms and Abbreviations

Abbreviation	Description
AFB	Application Function Block
‘C’ UDFB	a user-defined (PLC) function block implemented in ‘C’
DHCP	dynamic host control protocol
EMS	Energy Management System
FBD	function block diagram (IEC 61131-3)
FB	Function block (non-application specific)
FTP	file transfer protocol
GOOSE	Generic Object Oriented Substation Events
GUI	Graphical user interface
HTTP	hyper-text transfer protocol
IED	intelligent electronic device (e.g. IEC 61850 compliant)
IPv4 and IPv6	internet protocol version 4 and 6
MAC	media access control (protocol)
MCS	Monitoring and Control System
MMS	Manufacturing Message Specification
PMU	Phasor Measurement Unit
PDC	Phasor Data Concentrator [5]
PLC	Programmable Logic Controller: including combinational and sequential logic and linear and non-linear processing of sampled-data signals. For further clarification and also to http://en.wikipedia.org/wiki/Programmable_logic_controller
PhC	Phasor Controller
RAM	*volatile* random access memory
RoCoF	rate of change of frequency
SFTP	secure file transfer protocol
SSH	secure shell protocol
ST	Structured Text (IEC 61131-3)
TCP	transmission control protocol
TPCOM	tele-protection communications single board computer (SBC)
TPSA	Tele-protection stand-alone (TPCOM + daughter i/o boards)
UDFB	user-defined (PLC) function block
UDP	user datagram protocol
WAMS	Wide-area measurement systems
WAMPAC	Wide-Area Monitoring Protection and Control
WAN	Wide-Area Network

1 Introduction

1.1 Background

Alstom Grid (AG) is a partner with National Grid (NG), Flexitricity (FLX), Belectric (Bel), Centrica (Cen), University of Strathclyde (UoS) and The University of Manchester (UoM) to deliver the SMART Frequency Control (SFC) Project.

Alstom has committed to delivering consulting services and providing support for project partner demonstrations, and will contribute development of a Monitoring and Control System (MCS) platform (both hardware and software applications) [1] . This document defines the detail and scope of the Control Platform, also referred to as PhasorController (PhC) throughout the course of this document.

The PhC is a flexible hardware platform which is expected to be deployed within a power grid as a central part of Wide-Area Monitoring Protection and Control (WAMPAC) applications. In such applications, PhCs will typically analyse synchrophasor measurements received from multiple PMUs and/or PDCs to produce one or more binary trip or analogue control signals.

PhCs may be deployed stand-alone or in groups and may be co-located or distributed across a suitable IP network.

Deployed PhCs may act autonomously or collaboratively to improve overall grid synchronism or to manage another aspect of grid behaviour, such as providing the fast reallocation of generating resources in case of highly varying demand and/or supply.

When acting collaboratively, PhCs may be deployed in identical roles with different configurations reflecting their position within the power grid. PhCs may also be deployed with different roles and functionality, to act as complementary elements of a larger grid management function.

1.2 Problem Description

Today's Power Grids are evolving to incorporate more diverse generation resources, such as renewable energy resources. The increasing complexity of the grid management due to more rapidly changing supply as well as demand, the need to drive down costs through improvements in plant utilisation, and the reduction of system inertia as a result of asynchronously connected generation, means that more sophisticated and responsive grid management tools are becoming imperative.

Our experience with PhasorPoint (Alstom's commercial WAMS platform[1]) has shown that multipoint wide-area phasor measurements can help to optimize the grid management and can potentially be used for the dynamic control of power network resources. The availability of wide-area networks and synchronized measurement technology (PMUs, Data Concentrators and communication infrastructure) has enabled the gathering of phasor measurements comprising current and voltage phasors together with frequency, RoCoF and analog measurements (e.g. Power) and digital indicators(e.g. availability). Analysis of such data by a controller platform, together with its associated synchronisation and quality meta-data, can derive control signals to improve the stability of power grids, both today and in the future.

Therefore, there is increasing demand for a flexible programmable controller platform with a guaranteed response time suitable for WAMPAC applications, that are capable of evolving throughout its deployed lifetime to meet ever more complex challenges. To address this requirement, the PhC 'Control Platform' provides an open IEC 61131-3 PLC [3] program execution environment capable of running diverse control application schemes consisting of interconnected application function blocks (AFBs). Each AFB (e.g. Regional Aggregator function block for SFC) encapsulates the sophisticated analysis required to identify a specific grid phenomenon and determine the optimum control action, by utilising the wide area and local measurements, including the meta-data. The modularity of such schemes and their implementation in a PLC environment facilitates the development, extension and optimisation of the schemes - by Alstom engineers as well as customers. The schemes may be

[1] http://www.alstom.com/products-services/product-catalogue/electrical-grid-new/control-room/wams/phasorpoint/wams-products/phasorpoint-system/

formulated to meet demanding customer requirements for aspects such as response times, robustness and computational efficiency.

❖ This specification summary describes the PhC platform and does not describe any specific power system behaviour or any PhC application devised to influence it.

1.3 Project Objectives

The key objectives of this project in terms of the PhC control platform are to;

- Provide a high-performance, real-time synchrophasor analyser with very short response latencies[6];
- Provide an IEC 61131-3 PLC engine capable of running customer designed applications, i.e. applications that are not simply configured by Alstom for a given deployment but with functionality that can be tailored by the customer after initial deployment;
- Be a platform providing Alstom's high-value Application Function Blocks (AFBs) to customers for inclusion in either complete Alstom applications or bespoke/tailored applications as per 2nd item above;
- Provide the ability to interconnect multiple PhCs to form an integrated WAMPAC System
- Provide the ability to accept high-level management control and report the controllers' state and actions, for supervisory oversight; and provide the interfaces required to integrate PhC into a substation environment, such as specified in IEC 61850.

1.4 Requirements language

The terms '**must'**, '**must not**', '**should'**, '**should not**' and '**may'** are used in this specification in accordance with IETF RFC 2119. The term '**shall'** is used synonymously to mean '**must'**.

Must or **shall**	Mandatory requirement
Must-not	Mandatory prohibition
should	Recommended except in defined circumstances
Should-not	Prohibited except in defined circumstances
May	An optional requirement: systems claiming inter-operation with such a system must cope with the case where the other equipment does <u>and</u> does not implement optional requirements.

2 High-Level Requirements

The high-level requirements for the PhC Control Platform have been identified as follows:

- The PhC shall receive up to 30 synchrophasor streams, encoded in C37.118 format [2] from one or more PMUs and/or PDCs. Each PDC stream may contain up to 10 PMU measurement sets. Each C37.118 stream shall have a configured frame rate of 50 fps. Hence a PhC can handle up to 300 PMUs in total.
- The PhC shall continuously analyse C37.118 synchrophasors streams and produce outputs as determined appropriate by the application, typically within a single synchrophasor cycle (i.e. 20ms at 50Hz).
- The PhC control platform shall include an IEC 61131-3 PLC engine capable of running customer designed applications.
- For deployment within one or more PhCs, both Alstom engineers and customers shall be able to develop or modify PLC programs using a configuration tool. Typically, this may involve editing of function block diagrams (FBDs). PLC programs implemented in the form of an FBD may include;
  - ➢ Alstom’s high-value Application Function Blocks (AFBs);
  - ➢ Standard FBs provided by the configuration tool;
  - ➢ Custom FBs implemented as structured text (ST).
- The PhC platform may provide the capability for PLC applications to accept high-level management control from a supervisory WAMS. The PhC may provide the capability to report its state and actions to a WAMS to enable supervisory oversight. If required, these capabilities shall be implemented using the IEC 61850 MMS protocol (part 8 of [4]). At initial deployment, MMS control and reporting may not be provided. Instead a simple remote terminal session may provide sufficient access for high-level management control and logging.
- When deployed, a PhC shall be capable of accepting control inputs from IEDs and issuing control outputs to IEDs using IEC 61850 GOOSE frames.
- When deployed, a PhC shall be capable of accepting control inputs and issuing control outputs using IEC 60870-5-104 protocol. Interaction with a supervisory system may also be provided using IEC 60870-5-104.
- When deployed, a PhC may be capable of “real-time” control i/o [6] and supervisory control and monitoring using Modbus. (This capability would be provided at additional cost.)
- When deployed, a PhC may provide limited analogue and digital/binary inputs and outputs.

3 Technical Specification

PhC exploits an existing Alstom hardware and software platform. The following sections summarise its specifications and architecture.

3.1 Hardware Platform

The PhC hardware comprises of an enclosure containing a single-board computer. The single board computer comprises of a quad core CPU with up to 1.2GHz, 1GB RAM and 1GB Flash disk. One Ethernet controller of the CPU is connected to the 100BaseT (RJ45) admin port, through which the PhC will be configured during commissioning. The remaining 4 Ethernet controllers of the CPU are connected via three 3-port Ethernet switches and one FPGA to small form factor pluggable (SFP) sockets, which, for example, can be populated with 100FX Fibre SFPs.

3.1.1 Electrical Interfaces

Type	Connector	Qty	Role
Ethernet (IEEE 802.3u): 100 Mbit/s over 100base-TX (2 wire-pairs)	RJ45	1	user-control & reporting (SSH/MMS)
Ethernet (IEEE 802.3u): 100 Mbit/s over 100base-FX (2-strand optical fibre) or 100base-TX (2 wire-pairs)	SFP	1	IP based C37.118 syncrophasor i/p & o/p
Ethernet (IEEE 802.3u): 100 Mbit/s over 100base-FX (2-strand optical fibre) or 100base-TX (2 wire-pairs)	SFP	1	IEC 61850 GOOSE or IEC 60870-5-104

Table 3-1: Electrical Interfaces of the PhC platform.

3.2 Software Platform

A high-level view of the software architecture is shown in Figure 3-1 below.

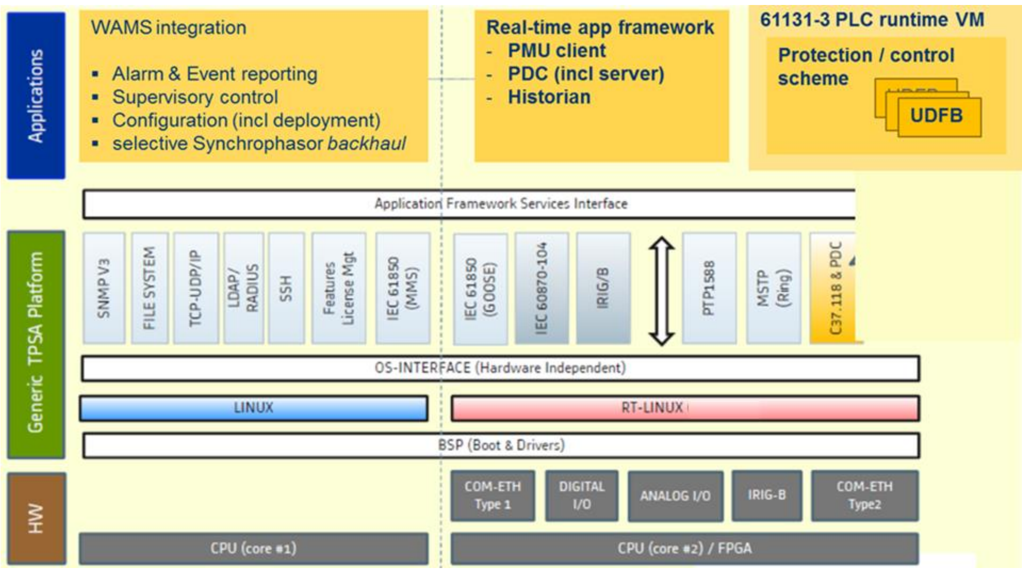

Figure 3-1: PhasorController Software Block Diagram. (The PhC platform only supports the protocols listed in Table 3-2.)

3.3 Operating System

The PhC platform is built on a Linux co-kernel operating system.

3.4 Protocols

Table 3-2 below lists the protocols supported by the PhC platform.

Type	Supported Protocols
Network stack	IPv4 and IPv6, TCP, UDP, DHCP, FTP/SFTP, SSH, HTTP
WAN synchronisation	PTP IEEE 1588-2002 (deferred to a later version)
Synchrophasor	IEEE C37.118-2014
Application Protocols	IEC 61850 (2003-2004) GOOSE inputs and outputs, IEC 61850 MMS (deferred to a later version), IEC 60780-5-104.

Table 3-2: Supported Protocols of the PhC platform.

3.5 Application Framework

Synchrophasor analysis and control output generation shall be implemented by PLC applications, each comprising a network of AFBs. Refer to section 4 for the PLC program development workflow.

The PLC program execution environment shall integrate user-configurable supporting functions (see section 3.6) that map external inputs and outputs to PLC program i/os and perform such functions as synchronisation, time-alignment and buffer management.

3.6 Configuration

The configuration of a PhC for a specific deployment shall involve editing of one or more plain text resource files. Resource files shall consist of pairs of resource names and values that the PhC shall typically read at start-up. This mechanism shall be used to configure the control application with such configuration settings as a PMU's IP address, a PMU-id an IED's Ethernet MAC address and other settings required by the specific control application.

3.7 Performance

The PhC platform shall be able to sustain continuous reception of the maximum number of C37.118 syncrophasor streams without any input data loss after reception by the PhC – except in the event of being taken offline for maintenance or power outage.

The maximum latency from a GOOSE input to a GOOSE output shall be <= 20 ms[1].This latency shall be met irrespective of the actual number of phasor streams consumed by a PLC program.

The maximum latency from a C37.118 input to a GOOSE output shall be <= 40 ms[2].This latency shall be met irrespective of the actual number of phasor streams consumed by a PLC program.

The latencies above shall only be met when no delay is applied by AFBs within the PLC scheme.

3.8 User Interface

Remote access to the PhC may be required to:

- Implement supervisory control actions (start, stop, …);

[1] Conforms with IEC 61850-5 type1b, class P2/3.
[2] This latency includes a minimum of 1 inter-frame interval, to enable the time-alignment of skewed arrival C37.118 frames.

- Allow review live status indications and retrieve log files;
- Retrieve (upload), edit and replace (download) configuration files; and
- Replace software components.

The PhC may not provide a graphical user interface (GUI).

Command-line-level remote access may be achieved over a secure shell (SSH) console. File transfer capabilities may be provided with secure protocols such as SCP/SFTP.

3.9 Data Logging

The PhC shall provide data logging functions to facilitate retrospective analysis of the PhC's response to an input scenario. This may improve the understanding of the scenario and/or reveal deficiencies of PLC programs or other software components.

Non-volatile (Flash) memory and volatile RAM are more limited on the PhC than would be the case on a desktop PC or server. The PhC does not have access to a disc drive and may not have continuous network access to a remote (disc) share.

The PhC shall textually log significant events to a log-file in Flash. Such events may include PLC program input and output events and PhC platform errors/warnings, for example relating to resource exhaustion. In the event that the log-file reaches a configurable maximum size, the oldest entries shall be deleted, to enable log entries to be appended.

The PhC shall manage a volatile circular buffer of C37.118 syncrophasor input data. When a 'significant event' is detected, the PhC shall copy a configurable amount of recorded input data before and after the event to non-volatile storage. Although no long-term record of the inputs from the power system is retained, this mechanism is intended to be sufficient for the purpose stated above.

4 Scheme Development Workflow

Alstom shall provide a library of opaque reusable application-specific function-block components (AFBs) in the form of UDFBs, that can be integrated in FBDs using a configuration tool.

Alstom engineers and customers shall have the capability to develop or modify PLC programs (*schemes*) by editing an FBD using the configuration tool.

AFB inputs and outputs bind values to their quality and synchronisation meta-data to simplify the scheme's external connectivity, reduce the number of internal connections and encapsulate the sophisticated treatment of values with meta-data within the AFBs.

References

[1] EFCC-SoW-001 “EFCC Statement of Work” (v1, 2015-01-07)

[2] IEEE C37.118.2-2011 “Standard for Sychrophasor Data Transfer for Power Systems” (2011-12-28)

[3] IEC 61131-3:2003 “Programmable Controllers part 3 programming languages”

[4] IEC 61850:2003-07 “Communications networks and systems in substations”

[5] IEEE PC37.244 “Draft Guide for Phasor Data Concentrator Requirements for Power System Protection, Control and Monitoring” (2012-06-19)

[6] Garre C, *et al.* “Real-Time and Real-Fast Performance of General-Purpose and Real-Time Operating Systems in Multithreaded Physical Simulation of Complex Mechanical Systems” (2014) Mathematical Problems in Engineering doi:10.1155/2014/945850