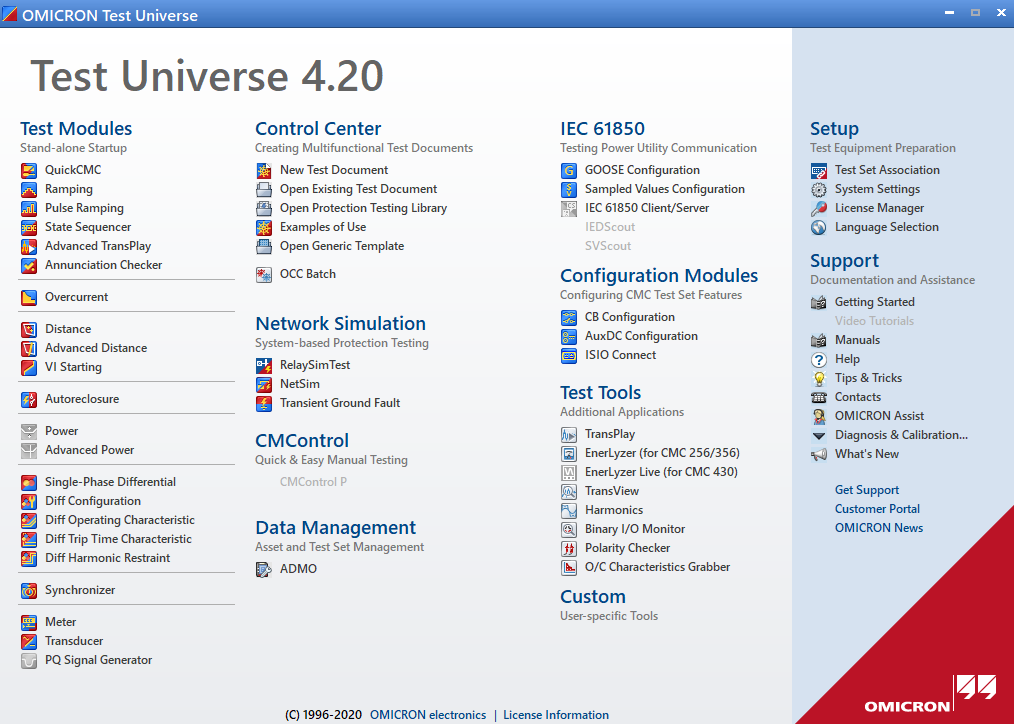
The protection relay testing procedure varies through its life-cycle of usage. The manufacturers performs type and production testing where as test engineers involved in commissioning and maintenance test of relays depends upon their role. The different method of testing used to determine and ensure performance of the relay while commissioning. The commissioning

carries function testing where installation of manual wiring, AC and DC control systems setup and relay testing where hardware tests carried (meter test, contact test, input/output circuitry), verification of hardware settings to avoid wrong operations. Then, automated testing evolved to fasten this process and generating a precise automated report for standard compliance. Also, it stopped manipulation of the results by the test engineers and established high standard relay schemes to settings. For instance, an automated test software namely OMICRON Test Universe provided an intuitive UI for controlling test parameters, creating,saving and playing test plans and generate automated report.

OMICRON TestUniverseTM



The OMICRON electronics GmbH created TestUniverse software as part of power system solutions. It provided varying sections and particularly test modules for different protection schemes. The test engineer choose desired module, enter nominal values for the relay in test, perform calculations, and limit test set outputs to the relay rated values.

In addition to that, the software TestUniverse enabled strong visualisation of test data’s in different views as time-signal plot, R-X complex diagram, and phasor diagram. The QuickCMC test module is the easiest and allowed manipulation of the test voltages (V) and currents (I). And Ramping is the most widely used module allows to ramp test quantities (magnitude, phase and frequency) up and down. The control center section enabled the faster and enhanced test automation where test engineers can create test plans using OCC files. The OCC files used to run a series of test modules, write a new setting for a test relay for the next test module and produced assessment reporting. As visible in the Figure Test Universe software facilitates many services namely network simulation, IEC 61850, configuration modules, test tools and so on. The entire setup and testing were physical dependent. Therefore, remote testing possibility of protection relays were explored through research and following sections will explain in detail.

Hardware in the Loop Based

<https://ieeexplore.ieee.org/document/8107191>

<https://ieeexplore.ieee.org/document/9176775>

<https://www.semanticscholar.org/paper/Hardware-in-the-loop-design-and-optimal-setting-of-Papaspiliotopoulos-Korres/22feb703cf308419ee3bb7c6e71c09892dbfb83d>

<https://www.researchgate.net/publication/317415795_Developing_automated_Hardware-In-the-Loop_tests_with_RTDS_for_verifying_the_protective_relay_performance>

<https://link.springer.com/chapter/10.1007/978-3-030-42274-5_4>

https://www.semanticscholar.org/paper/Real-time-Hardware-in-the-loop-Implementation-for-Avalos-Zamora/f54eb540ce59d7c5d505581284e4ab0a2f78e72b

The remote testing of protection relays researched and implemented through hardware-in-the-loop (HIL)simulation method. The time-domain protection approach must be tested in realistic before actual commissioning within the power substations to make sure reliability improvement. A HIL model with the distance relay SEL-421 was proposed and reported the performance of relay through a study [5]. Also, the assessment methods of HIL are researched in Europe as a guide [6] for Europeans where real hardware testing is necessary. Simulation enabled the possibility for reliability and flexibility without damaging physical equipments but usually hard to fully capture the real behaviour of the equipment. And real hardware testing requires more time to configure for adaption and investments. HIL approach interfaced the simulation and real-hardware environment as efficient testing method for emerging Distributed Energy Resource (DER) devices, manufacturers to adapt, network operators and regulation authorities to establish new testing method from power system landscape. HIL allowed a real hardware setup to couple with real time simulator for testing hardware/software components under realistic conditions. It avoids simulation gaps in real-hardware as well as time consuming hardware reconfiguration with simulated values.

on Plenty of researchers introduce the ‘remote testing of protection relays’ concept for

educational and distance learning purposes. R. Zivanovic in his paper “Remote pro-

tective Relay Testing” proposes remote protective relay test method that comprises

the use of SEL low level test module and Application Service Provider (ASP) to

enhance troubleshooting testing performed by engineers on remote locations [26].

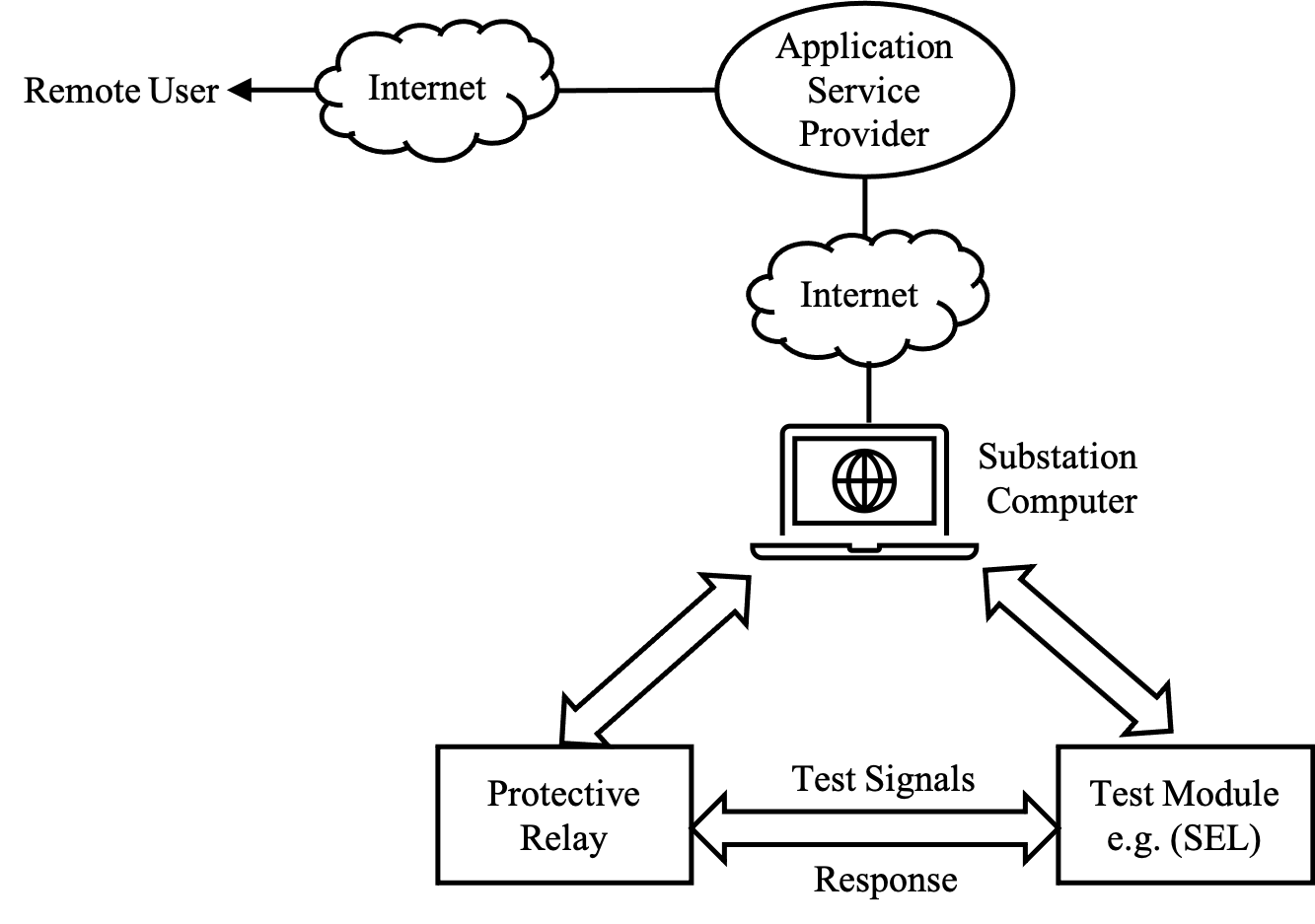
The Application Service Provider architecture used includes Authentication, test

management, results management and queue management for remote user interac-

tion with online experiments. A block diagram of this implementation is shown in

Fig. 4.5. Another similar proposition by V. Fernão Pires in the School of Setúbal to

implement a remote laboratory [11].



SV Based Testing

Omicron has made a step towards functional testing using their product CMC 256

with NET- 1 option that allows the generation of sampled value test quantities. The

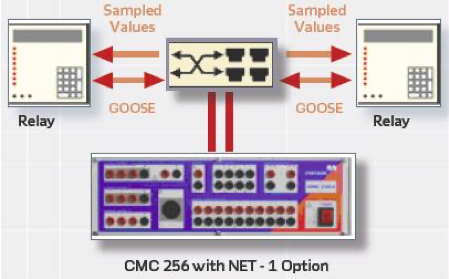
sampled values are generated according to the ”Implementation Guideline for Digi-

tal Interface to Instrument Transformers using IEC 61850-9-2”, which is published

by the UCA International Users Group [15]. This method is quite effective for con-

ventional wires reduction since the communication is established via ethernet based

communication link. Fig. 4.6 shows a simplified diagram of this testing philosophy.



Web Based Remote Testing

Lately, Sprecher Automation developed a Web application The IED under test is

the server and the remote user pc is the client as shown in Fig. 6.1. Ideally, The

Server App runs the protection algorithm in the physical IED and data is sent and

retrieved using the https internet communication protocol. However, the Web app

is implemented for prototyping using WebAssembly technology [12]. WebAssemply

enables users to run native language applications in the web browser using the

Emscripten compiler. Emscripten compiles the C source code and generates 3 files

(.wasm, JavaScript and HTML) that can be loaded into the browser.

The user in the remote location is able to upload two files, an IED settings file

and a test file where the testing samples are stored. The user has two test file

formats possibilities to use. COMTRADE file format [1] or CSV file format. Most

disturbance recorders and automated test software store the data in COMTRADE

format, therefore, it was chosen in this approach.

The CSV format was chosen to make use of the OMICRON OCC files concept

where the user can store the data stored in an OCC file into a CSV file using

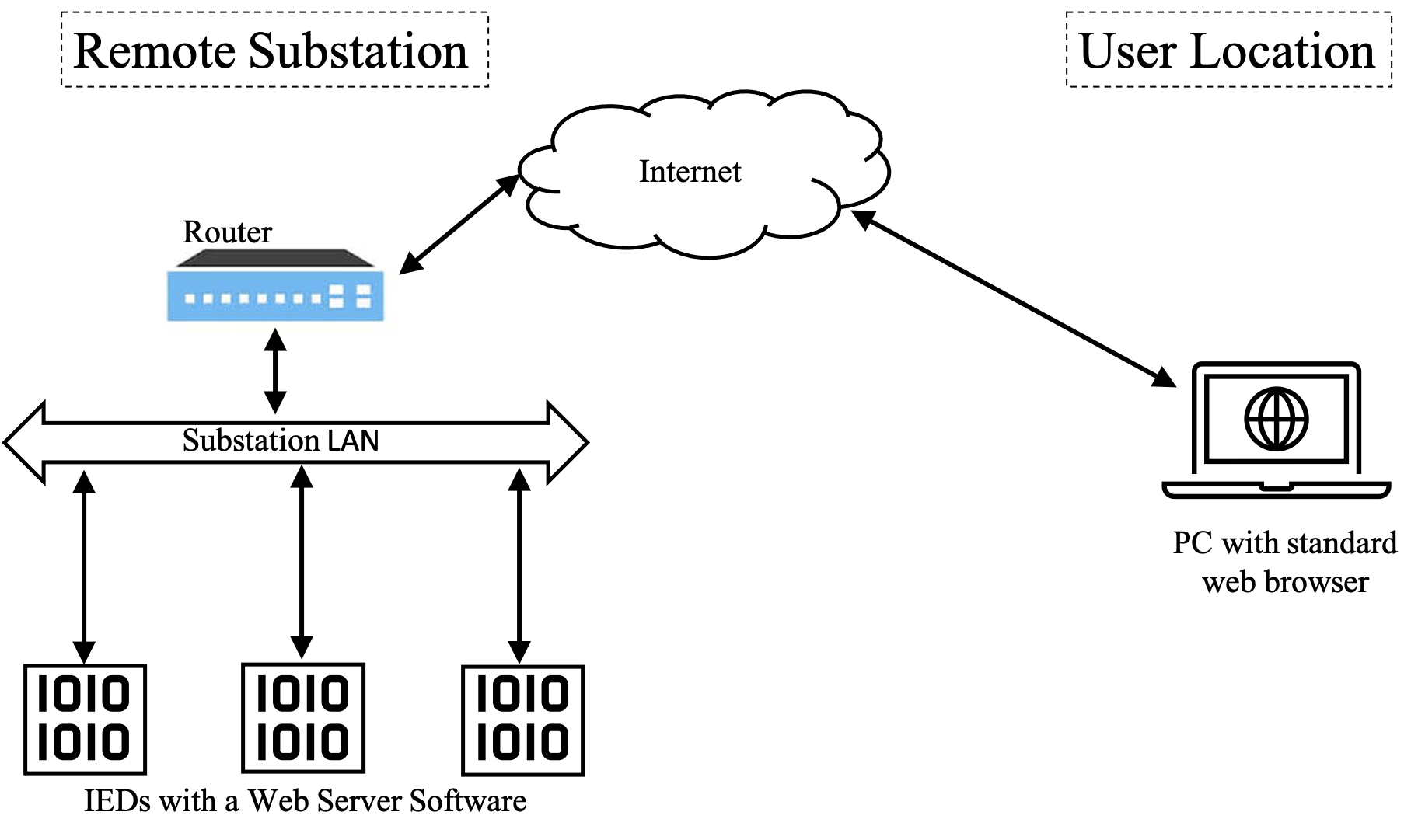
the ”OCCinterpreter”. ”OCCinterpreter” is a C++ based program written for this

approach by the author. Additional, a Windows desktop application was created

based on the Microsoft C# .Net Framework. The windows application is created to

generate 3 phase system samples. The samples are stored in a csv file the user can

download to be used fot the Web app.



Test Setup

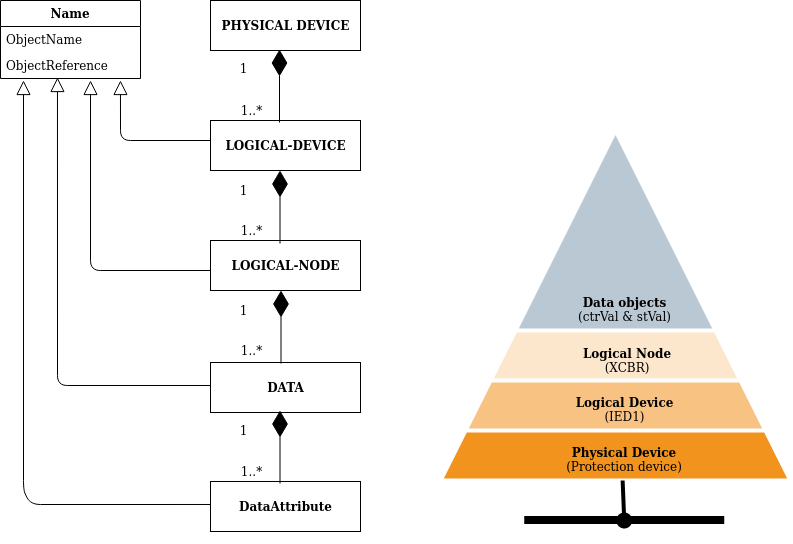
Test Procedure

Test Results

IEC 61850

In a nutshell, IEC 61850 standard introduced for substation automation. The substation comprise of electronic equipments(circuit breaker, relay etc.) used for monitor, control and protect to avoid network outages. Main purposes were for interoperability and integration between various vendor equipments (IED’s), more structured approach, separate data model from the communication, intuitive device and data modelling, fast and convenient communication, lower cost for installation,

configuration and maintenance.



The IEC 61850 standard specified a hierarchical data model as figure b. Every physical device accessed through network addresses and contained one or more logical devices. The logical device are the collection of logical nodes implemented in one IED (protection, control) and core elements of IED61850 data model. Logical nodes are the real device functions e.g XCBR where X defined switchgear and CB for circuit breaker and PDIF where P stands protection and ID for differential protection. Every logical nodes contains collection of mandatory/non-mandatory data objects to realise function objective. For instance, XCBR logical node has data objects with status information and controls. Then data attribute are properties of logical nodes with stVal (status value) or ctrVal (control value), Loc for local or remote control.

IEC data Exchange model and communication protocol

Client server architecture

The clients (SCADA gateway) establish a connection to servers (IEDs) which contains the data. It uses Manufacturing Message Specification (MMS) communication based on TCP/IP between server and client for read/write configuration data of IED, control equipments data on high voltages (circuit breakers, disconnectors etc.), and report on every data instantaneously when a change occurs.

Generic Object Oriented Substation Event (GOOSE)

It is used to exchange event data between IEDs faster.

Sampled Value

This model used to exchange digital samples of an analog waveform in a communication network as a file. Also this approach necessitated Merging Unit (MU) for analog-digital conversion to deliver digital samples. The IED takes the samples at fixed sampling rate and tags with a counter for sampling time.

The GOOSE and SV follow publisher-subscriber communication model for real-time critical data excahnge required. It publisher who ahd data publishes using peer-to-peer channel and eligible subscriber receives it. This communication type also known as Ethernet Multicast with priority and qaulity of service with signalling delays less than 20 ms.

Standard Configutaion File (SCL)

Integration of IED in the substation posed tedious process and procedure due to different formats from varying vendors. Hence, a standardized specification established for substation configuration (for instance, equipment functions, device capabilities, connection, etc.). IEC61850-6 defined substation configuration file (SCL) contains hierarchy of config files to exhange data in an uniform way. The below are the list of files.

System Specification Description (SSD): It illustrated the topology of the substation for automation e.g single line diagram (SLD)

IED Capability Description: The vendor specific file used to define IED data model, capabilities and physical entity.

Substation Configuration Description: It describes the entire substation configuration. It is more of combination fo ICD and SSD file.

Confiugred IED description (CID): It contained necessary information of IED requirements e.g to initiate an exchange of data or data availability.

IEC substation architecture image

substation bus – it is medium bandwidth Ethernet network carries all ACSI requests/repsonses and substation event messages (GOOSE)

Process bus - it connects the IED’s to field devices (sensors, transformers etc) using a high speed network.

The bottom process level, measured power system voltages, currents, and status information are given input to merging unit for analog-digital conversion. The data are collected using Ethernet communication and published from an Ethernet Switch with a 1GB internal bus (process bus) and respective eligible IEDs can subscribe to it at the substation level. Further on, the data(read/write, comamnds, SV, GOOSE , etc.) communicated from Logical Nodes (IED) to Supervisory Control And Data Acquisition (SCADA) gateway from substation level. Also this enabled the possibilities of remote access with prominent security standard in place.

[https://www.kth.se/social/files/56014418f2765437d7cb0cd5/Lecture%207%20-%20Substation%20Automation%20with%20IEC%2061850.pdf](https://www.kth.se/social/files/56014418f2765437d7cb0cd5/Lecture 7 - Substation Automation with IEC 61850.pdf)