EPIC Final Report

Program	**Electric Program Investment Charge (EPIC)**
Administrator	**San Diego Gas & Electric Company**
Project Number	**EPIC-2, Project 3**
Project Name	**Monitoring, Communication and Control Infrastructure for Power System Modernization**
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Attribution

This comprehensive final report documents the work done in this EPIC project.

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Executive Summary

The objective of EPIC-2, Project 3 (Monitoring, Communications, and Control Infrastructure for Power System Modernization) was to demonstrate advanced monitoring, communication, and control infrastructure needed to operate an increasingly complex power system infrastructure. The chosen project focus was a demonstration of Open Field Message Bus (OpenFMB) with respect to San Diego Gas & Electric's (SDG&E) existing architecture and vision for the future. The project included assembly of a test system to demonstrate OpenFMB in a controlled environment within SDG&E's laboratory. This test system was used to execute specific use cases developed as part of this project, leading to a number of test results. Finally, these test results were analyzed to generate a number of findings and recommendations.

This project was one of three SDG&E EPIC projects on pre-commercial demonstration of communications standards for power system operations. The three projects were:

- Smart Grid Architecture Demonstrations
    - Focus: Communications standards for integration of feeder equipment and DER into networked automation
- Monitoring, Communication, and Control Infrastructure for Power System Modernization
    - Focus: Open Field Message Bus
- Modernization of Distribution System and Integration of Distributed Generation and Storage
    - Focus: IEC 61850 in substation network

The principal standard of interest in these three demonstrations was IEC 61850, which is an open standard developed by industry stakeholders and promulgated through the International Electrotechnical Commission. The intent of these EPIC demonstrations is to increase the body of knowledge available to aid users in making decisions regarding their future power system communications architecture. The final reports for all three of these projects are posted on the SDG&E EPIC website at www.sdge.com/epic

OpenFMB is an effort coordinated by the Smart Grid Interoperability Panel (SGIP) and standardized by the North American Energy Standards Board (NAESB). OpenFMB consists of a framework and reference architecture comprised of a variety of existing standards to enable a publish/subscribe smart grid field message bus. OpenFMB is designed to enable distributed intelligence, with peer-to-peer communication, as well as ease integration by extending the life of field assets through the use of adapters to legacy protocols.

The test system consisted of several controllable utility distribution system devices networked to mimic two feeders on SDG&E's production distribution network. These devices were networked using differing network technologies designed to reproduce field conditions. The project also demonstrated communications interoperability among different vendor products through the use of adapters which converted those products' legacy communications technologies to OpenFMB.

The OpenFMB network then used multiple communications protocols, including MQTT, DDS, and R-GOOSE, to accomplish the 13 use cases developed for this project. Finally, the demonstration system was subjected to a number of test cases to verify its correct operation and validate the use cases.

During the testing of the demonstration system, results were captured using a variety of methods such as network packet captures, oscillography, and sequence of events. These results were then analyzed to develop a number of findings and recommendations. As a result of this demonstration, it was found that OpenFMB is not yet a standard for peer-to-peer interoperability. Gaps and options in OpenFMB's definitions are hindrances to achieving interoperability. For the purposes of this project, many of these aspects were defined to create a complete demonstration system. However, further work on unambiguous definitions in the standard would aid its potential commercialization. Such definitions would provide guidance and confidence to vendors considering integration of OpenFMB into their products and, subsequently, would provide market confidence in OpenFMB.

It was also found that OpenFMB allows use of peer-to-peer communication, rather than traditional hierarchical communication between devices and the utility back office found in most currently deployed distribution systems, and the autonomy of distributed intelligence unlocks the potential for new use cases, such as distributed Volt/VAr control. Another potential use case that could drive adoption of OpenFMB would be the use of adapters on existing assets with limited communication capabilities to integrate them into a distributed intelligence network. An example is distributed energy resources (DER) that typically use Modbus for local communications via serial links, but are not capable of networked communication.

In conclusion, this project successfully demonstrated a complete OpenFMB network. The test system demonstrated the power of distributed intelligence as well as the architectural flexibility provided by adapters. While it was found that work remains to further define and mature the OpenFMB standard, it was also found that OpenFMB clearly shows promise as a framework in addressing the objective of this project. It is recommended that work be continued to further define the OpenFMB standard so that it can be successfully utilized in future utility distribution system projects and deployments.

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List of Acronyms

ADMS	Advanced Distribution Management System
AMQP	Advanced Message Queuing Protocol
ANSI	American National Standards Institute
CIM	Common Information Model
CoAP	Constrained Application Protocol
CPUC	California Public Utilities Commission
DDS	Data Distribution Service
DER	Distributed Energy Resource
DERMS	Distributed Energy Resource Management System
DNP	Distributed Network Protocol
EPIC	Electric Program Investment Charge
ESB	Enterprise Service Bus
FAT	Factory Acceptance Testing
FERC	Federal Energy Regulatory Commission
FTP	File Transfer Protocol
GB	Gigabyte
GE	General Electric
GHz	Gigahertz
GOOSE	Generic Object-Oriented Substation Event
HMI	Human-machine Interface
HTTP	Hypertext Transfer Protocol
IEC	International Electrotechnical Commission
IED	Intelligent Electronic Device
IoT	Internet of Things
IOU	Investor Owned Utility
IP	Internet Protocol
ISO	International Organization for Standardization
IT	Information Technology
ITF	Integrated Test Facility
Kbps	Kilobits per second
kW	Kilowatt
LAN	Local Area Network
MB	Megabyte
Mbps	Megabits per second
MHz	Megahertz
MQTT	Message Queue Telemetry Transport
NAESB	North American Energy Standards Board
NERC	North American Energy Reliability Corporation
NIST	National Institute of Standards and Technology
OASIS	Organization for the Advancement of Structured Information Standards
OMG	Object Management Group
OPC UA	OPC Unified Architecture
OpenFMB	Open Field Message Bus

PMU	Phasor Measurement Unit
PV	Photovoltaic
R-GOOSE	Routable-Generic Object Oriented Substation Event
RAM	Random Access Memory
RMQ	Retail Market Quadrant
RTDS	Real Time Digital Simulator
RTU	Remote Terminal Unit
SAT	Site Acceptance Testing
SCADA	Supervisory Control and Data Acquisition
SDG&E	San Diego Gas and Electric
SDO	Standards Developing Organization
SEPA	Smart Electric Power Alliance
SGIP	Smart Grid Interoperability Panel
TCP/IP	Transmission Control Protocol/Internet Protocol
TLS	Transport Layer Security
UDP	User Datagram Protocol
UML	Unified Modeling Language
WAN	Wide Area Network
XML	Extensible Markup Language
XSD	XML Schema Definition

1 Introduction

1.1 Project Objective

The objective of the pre-commercial demonstration of EPIC-2, Project 3 (Monitoring, Communications, and Control Infrastructure for Power System Modernization) was to demonstrate advanced monitoring, communication, and control infrastructure needed to operate an increasingly complex (“smarter”) power system infrastructure.

This project was one of three SDG&E EPIC projects on pre-commercial demonstration of communications standards for power system operations. The three projects were:

- Smart Grid Architecture Demonstrations
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EPIC-2, Project 3 sought to address the following problems:

- Interoperability issues and challenges
- Peer-to-peer communication thus enabling distributed applications and avoiding brittle centralized command and associated latencies
- Integration challenges with using multi-protocol conversions
- Benefits and challenges with distributed intelligence

The project’s chosen specific focus was to:

- Demonstrate and evaluate the Open Field Message Bus (OpenFMB) framework within SDG&E’s existing architecture and its vision for the future operations of its distribution system.
- Demonstrate and evaluate the use of OpenFMB in the monitoring and control of a distribution network.

- Development of a test system (pre-commercial demonstration as per EPIC guidelines) to evaluate and demonstrate OpenFMB in a controlled environment within SDG&E's laboratory.
- Demonstrate the capabilities of an OpenFMB field messaging bus architecture and how a control portal along with an optimizer can be deployed on the OpenFMB network and can enable the communication and visualization of network diagrams, display and monitoring of field devices with measurement and status values.
- Demonstrate and document the use of the OpenFMB architecture to validate the pre-defined use cases.
- Demonstrate the salient features of OpenFMB such as:
  - Distributed intelligent devices and the opportunity to manage grids locally, in a manner suitable to local needs and conditions.
  - Demonstrate OpenFMB framework with field devices such as relays, reclosers, capacitors, switches, inverters and other devices that communicate to each other and take intelligent actions locally.
- Provide recommendations regarding the future use of OpenFMB and prospective next steps, based on the demonstration results and metrics.

1.2 Issue/Problem Being Addressed

The modern electric power system will be designed for two-way power flow in distribution circuits, in contrast to the traditional value chain of one way power flow from large generation systems through the transmission and distribution systems to the load. New intelligent devices that support varied functionality and features are being deployed along the transmission system, within substations, along the distribution feeders, and behind the meter at customer premises. These devices use various alternative information models and communication protocols, many of which are proprietary in nature. This inhibits devices from communicating peer-to-peer with other devices in the field, thereby hindering interoperability and making it difficult to exchange data and information for local intelligence and decision making. Additionally, distributed sources of energy are injecting power into the utility distribution system, which require new devices capable of handling the power flow. This has resulted in the traditional centralized control systems evolving into a more hierarchical model that leverages the traditional centralized control and the added distributed control.

To enable this evolving model, a new framework for monitoring, communication and control infrastructure is required. The Smart Grid Interoperability Panel (SGIP) and North American Energy Standards Board (NAESB) have been developing an open standard for utility field device interoperability. Open Field Message Bus (OpenFMB) is a specification for non-proprietary and standards-based field message bus to enable various power system field devices to interoperate. OpenFMB is intended to be used by the stakeholder community of utilities and vendors to develop the technical requirements on field devices that enable them to communicate directly with each other via a field message bus as well as with centralized data centers as they do today, without a significant increase in the integration cost or complexity. It is a framework for utilities to securely access field data and share it between all devices and systems. OpenFMB leverages proven internet protocols (IP) for improved interoperability and situational awareness. Adoption of IP-enabled technology can be scalable to support existing power system infrastructure

1.3 Project Approach

The project plan was organized into three phases:

- Phase 1 – SDG&E Internal Project Work Prior to contractor procurement that includes
    - Task #1 - Development of Project Plan
    - Task #2 – RFP Development
    - Task #3 - RFP Release, Proposal Evaluation, and Vendor Selection
    - Task #4 - Contracting, Procurement, Resourcing, and Kick-Off
- Phase 2 – Project Development Activities
    - Task #5 – Evaluate OpenFMB Framework within SDG&E Architecture
    - Task #6 – Develop Pre-Commercial Demonstration System for Testing in ITF (Integrated Test Facility)
    - Task #7 – Pre-Commercial, Demonstration, and Analysis
- Phase 3 – SDG&E Internal Project Work prior to project conclusion
    - Task #8 – Finalize Project Report for External Release
    - Task #9 – Technology Transfer Plan

Phases consisted of sub-tasks, each of which has a report documenting the activities and results. Table *1* presents the phased approach used in the pre-commercial demonstration activities.

Table 1 – EPIC-2, Project 3 Pre-Commercial Demonstration – Phased Approach

Phase	Task
Phase 1 – SDG&E Internal Project Work Prior to contractor procurement	Task #1 - Development of Project Plan
	Task #2 - RFP Development
	Task #3 - RFP Release, Proposal Evaluation, and Vendor Selection
	Task #4 - Contracting, Procurement, Resourcing, and Kick-Off
Phase 2 – Project Development Activities	Task #5 – Evaluate OpenFMB Framework within SDG&E Architecture
	Task #6 – Develop Pre-Commercial Demonstration System for Testing in ITF
	Task #7 – Pre-Commercial Demonstration, and Analysis
Phase 3 – SDG&E Internal Project Work prior to project conclusion	Task #8 – Comprehensive Final Report
	Task #9 – Technology Transfer

1.3.1 Phase 1 – SDG&E Internal Work Prior to Contractor Procurement

Task 1 – Development of Project Plan

Objective – Develop detailed work plan for the project.

Approach – The project team met with internal stakeholders to conduct a review of existing systems for monitoring, communication and control of the power system and the plans for ongoing development of these systems. Following activities were reviewed with the stakeholders:

- OpEx2020 vision and Vision 2030
- Projects ongoing under EPIC-1
- Advanced Distribution Management System
- Distributed Energy Resource Management System

The project team identified conceptual, functional and system requirements for the pre-commercial demonstration project. These requirements were identified by reviewing SDG&E's existing plans and high-level use cases to identify key systems and their interactions for key modes of operation. The project plan identified staffing requirements for the project, both internal and contracted, with definition of needed skills. Required equipment and other resources were also identified.

Output – Project work plan including technical scope definition, schedule, budget, and staffing requirements was developed.

Task 2 – RFP Development

Objective - Develop RFP for competitive procurement of contractor services for the requisite phases of the technical scope.

Approach – An RFP was developed for the contracted portion of the work, the contained the following sections:

- Brief Project Background
- Statement of Project Objective
- Scope of Work
- Approach
- List of Deliverables
- Expectations for Tech Transfer Plan
- Project Schedule
- Selection Criteria
- Solicitation Schedule
- Encouragement for Bids with DBE Participation

The RFP was sent to multiple recipients. The proposals expected from the respondents included (at a minimum):

- Meeting the requirements of the RFP (being responsive)
- Proposed technical approach for performing the work
- Concept of operations and system architecture
- System infrastructure specifications
- Test plan for testing at SDG&E facilities
- Measurement, verification and analysis of data
- Findings and recommendations, based on the results
- Tech transfer plan for use of project results
- Reporting to SDG&E
- Conformance with CPUC EPIC Decision 12-05-037 and other relevant EPIC decisions

The selection criteria (at a minimum) addressed the responsiveness of the bidder to the RFP requirements, elaboration on technical approach, cost, bidder experience and company qualifications, DBE participation, team structure, management plan, qualifications of individual team members, proposed schedule, cost, and acceptance of SDG&E Terms and Conditions. Bidders were encouraged to include DBE companies in their project team.

Output – RFP document was developed for release to recipients.

Task 3 – RFP Release, Proposal Evaluation, and Vendor Selection

Objective - Release RFP to external recipients, evaluate proposals received and shortlist prime contractor.

Approach - Worked with SDG&E supply management to release the RFP and manage the contractor selection. Obtained bidder responses from supply management and organized for stakeholders review during the evaluation process. Received proposal submittals were be validated, a proposal review team was established and a proposal review schedule was developed. Developed detailed evaluation criteria that evaluated the technical and financial response from the bidders. Scoring criteria incorporated an individual scoring sheet and a consolidated scoring workbook will be developed. Formed an internal proposal and project review panel of SDG&E subject matter experts from stakeholder groups to use the project results. Subsequent to developing the evaluation criteria, responses were sent to the review panel for review and scoring. Two review panel meetings were conducted to review the scores and discuss the proposals. During the evaluation process the scoring matrix was populated to get a clear picture of strength of the bidders' proposals. Proposals were reviewed along with the scoring approaches and scoring criteria. Follow up technical questions were developed for clarification from bidders. The proposals were evaluated to assess proposer's assumptions on SDG&E team activities and identify project risks. Evaluation workshops were conducted for bidders who meet the criteria to be vetted further, and necessary discussions on the technical aspects of the SOW and other terms and conditions were conducted that culminated in the selection of a vendor.

Output – Vendor selection including proposal evaluation matrix, scoring matrix and identification of the selected vendor.

Task 4 – Contracting and Procurement

Objective – Procurement of selected contractor services under contract with Supply Management.

Approach - Engaged with the selected contractor in contract discussions to finalize the scope of work, schedule and budget for the project deliverables. The following documents were developed and finalized as part of the contracts package:

- Detailed scope of work
- Detailed project schedule
- Detailed Project Budget
- Professional services agreement

Output – Prime contractor agreement was finalized with SDG&E supply management and the contractor.

1.3.2 Phase 2 – Project Development Activities

This section describes the project development activities that were undertaken by the project team that included SDG&E resources and the prime contractor resources. The project undertook an evaluation and demonstration of the OpenFMB specification within the context of SDG&E's existing architecture and vision for the future of its grid operations. The project also undertook a pre-commercial demonstration to evaluate and demonstrate OpenFMB in a controlled environment within SDG&E's laboratory. The pre-commercial test system was also used to demonstrate specific use cases developed as part of the project.

Task 5 – Evaluate OpenFMB Framework within SDG&E Architecture

Objective – Evaluate OpenFMB Framework within SDG&E Architecture

Approach - In this task, the OpenFMB framework was evaluated with respect to SDG&E's specific architecture. This phase the development of reference architecture, demonstration architecture, use cases and associated test cases. The reference architecture described how OpenFMB could be incorporated into SDG&E's production environment and is further detailed in Section 3.2.1. This reference architecture followed the approach detailed in NAESB RMQ.26 and specifically detailed a logical architecture and a node architecture. In addition, it was shown how OpenFMB could be incorporated into SDG&E's specific production environment, in the near term and long term.

The demonstration architecture describes the specific implementation of the project's OpenFMB test system and is further detailed in Section 2.3. This demonstration architecture is a subset of the overall project reference architecture and was used to create the test system. The power system equipment selected represented a range of vendors, device types, and native protocols (e.g., DNP3, Modbus), as shown in Table 2.

The use cases developed were created to demonstrate the use of OpenFMB in a variety of field scenarios. These use cases included both non-functional requirements and also addressed known business needs. The use cases were then used to create the needed data profiles for communicating between the various devices. Test cases were also created in conjunction with the use cases to verify their correct operation and to better understand the operation and usefulness of OpenFMB.

Output – OpenFMB Framework within SDG&E Architecture for pre-commercial demonstration

Task 6 – Develop Pre-Commercial Demonstration System for Testing in ITF

Objective - Design and develop pre-commercial test system incorporating the OpenFMB demonstration architecture for testing at the ITF.

Approach - In this task, a test system was designed and developed for demonstration at SDG&E's ITF, leveraging existing products. This test system realized the demonstration architecture developed in the first phase and was used to implement the use cases developed.

Adaptors were configured to interface with the various equipment in their native communication protocols (e.g., DNP3, Modbus). These adaptors converted the data into the format described by the data profiles and then sent the data over MQTT or DDS.

The test system devices were also interfaced with a power system simulator. This simulator was configured to mimic actual power system conditions and the test system was realized on a simulation of two actual SDG&E feeders. The simulator was also used during testing to simulate anomalous conditions in the power system, thus exercising the use cases. A detailed communications infrastructure was designed and developed to demonstrate a variety of communications technologies and inter-networking. The various adaptors were then integrated into the communications infrastructure to realize a field message bus.

Output – Development and integration of pre-commercial demonstration system for testing at the ITF.

Task 7 – Pre-Commercial Demonstration, and Analysis

Objective - Conduct demonstrations for the pre-commercial test system at the ITF, and analyze the results

Approach – In this task, the pre-commercial system underwent testing at the contractor's facility prior to installation at SDG&E's ITF. This initial demonstration provided opportunity for feedback and further refinement of the test system and culminated in FAT. Subsequently, the test system was integrated into SDG&E's ITF. This installation included integration with the onsite power system simulator and placement into the facility. Once installed, the test system was exercised using the previously developed test cases for pre-commercial demonstration. Data was collected during the demonstration, including network packet captures and oscillography. This data formed the basis of the findings and recommendations presented in Task 8 (this report).

Output – Pre-commercial demonstration and analysis of the OpenFMB test system

1.3.3 Phase 3 – SDG&E Internal Project Work Prior to Project Conclusion

Task 8 – Comprehensive Final Report

Objective – Develop comprehensive final report

Approach - Develop a comprehensive final report based on the CPUC EPIC Final Report guideline developed by the three IOUs. The report presented in this document follows the outline developed by the IOUs to share the results of the project undertaken.

Output – Comprehensive final report as presented in this document.

Task 9 – Technology Transfer

Objective – Develop technology transfer plan to share results with all stakeholders.

Approach – A technology transfer plan was developed to share the results with SDG&E stakeholders and with other stakeholders in the industry that would benefit from this pre-commercial demonstration

Output – Technology transfer plan as documented in Section 4 of this report.

2 OpenFMB Pre-Commercial Demonstration System

2.1 OpenFMB Overview

OpenFMB is an IoT framework designed and supported by SEPA (formerly SGIP) and standardized in NAESB as NAESB RMQ.26. OpenFMB is focused on providing an open field message bus framework using well-known and widely-adopted standards and industry-standard semantics as well as a reference architecture and common approach to development. Interfacing to other existing standards is accomplished through the use of adapters. OpenFMB is focused on field device interoperability and enabling secure, peer-to-peer communication through a publish/subscribe model, often without the need to communicate with central office head-end systems.

2.2 Publish/Subscribe Protocols

One of the requirements for OpenFMB is that it uses publish/subscribe or "pub/sub" protocols. That's a foundational element of OpenFMB that differentiates it from frameworks for handling field device messaging. Pub/sub generally describes a messaging pattern. It is an alternative to other messaging patterns such as the client-server model, e.g., used for Hypertext Transfer Protocol (HTTP) or File Transfer Protocol (FTP) technology. In that model, a client specifically requests information from or sends information to a server. This is a more "tightly coupled" relationship, in that the client knows precisely which server to communicate with and, typically, the server knows which client is trying to communicate.

In the pub/sub model, publishers have data that is published out often through what is referred to as a "topic." For example, if the publisher is a smart thermostat, the topic might be temperature. Authorized subscribers subscribe to that topic and thus they can pull temperature data. In that arrangement, the publisher and subscriber are more loosely coupled than in the client-server approach, because subscribers don't necessarily know the publishers and vice versa. One publisher could push out a topic to a large number of subscribers. Subscribers, in turn, could receive just one topic from one thermometer or it could subscribe to any number of topics from any number of publishers.

Mutual "awareness," if you will, is possible, but not required as it is in the client-server model. The key is that a subscriber is more focused on the topic than on the node it is talking to. All traffic in the pub/sub approach is subject to security protocols and publishers only publish and subscribers only receive topics for which they are authorized. Security protections are in place.

The thinking behind OpenFMB is that the pub/sub model should be a more effective model than client/server for multiple devices in a field network to communicate with one another. But it is important to note that this debate is not settled. Some see advantages to the client-server model in field device networks. But SGIP and NAESB have chosen to use the pub/sub model in the OpenFMB guide they've approved for field device networks.

2.2.1 'Broker' and 'brokerless' approaches

A further distinction with the OpenFMB's use of pub/sub should be noted. Some OpenFMB protocols use "brokers" while others are "brokerless," while some are able to do both.

A broker may be thought of as a node or device that serves as a middleman in pub/sub communications. In broker scenario, when a publisher publishes a topic it goes to a broker, which then queues it up for, and delivers to, authorized subscribers. Subscribers seeking to pull topics from publishers first go to the broker to subscribe, which pulls data from publisher. The broker is a single node or device that manages traffic between publishers and subscribers.

The role of the broker has pros and cons. Among the benefits that supporters cite is the broker's role in security enforcement, which means that that function is not distributed among publishers and subscribers. The broker performs easier routing of topics and makes discovery by either publisher or subscriber an easier task because two nodes have only one place to send topics or from which to receive topics. That means publishing and subscribing nodes need less programming code.

In a brokerless environment, all publishers are responsible for sending the appropriate data to all authorized subscribers. That means the publisher must "know" which subscribers are authorized and their addresses. Subscribers need to be able to find publishers and subscribe to them – that's the "discovery" process. That can become quite complex in a large network or a network with routers in them. It can become difficult for publishers and subscribers to find one another and it can be difficult to then manage publisher-subscriber connections, security conditions and so forth. The benefit of the brokerless arrangement is that there's no single point of failure. If a broker is used, it can fail or be overwhelmed by network congestion

2.2.2 OpenFMB and Multiple Protocols

OpenFMB, as written, provides a guide that identified (3) three choices for protocols, which provides flexibility for implementation. The three protocols, however, do not work together. With standards, there's always a trade-off: flexibility vs. interoperability. Three choices reflect flexibility. But those choices don't work together, so there's an interoperability issue between systems that make different protocol choices.

The OpenFMB guidance calls out three protocols for potential use: MQTT, DDS and AMQP. If one OpenFMB implementation uses MQTT, for ex., and another uses DDS, they won't talk to each other. But in a specific application, one choice can be explored for its efficacy.

If the application needs fast, real-time data, e.g., with a synchrophasor, DDS might be the choice. If the application calls for a wider, distributed network of devices, the best choice might be MQTT. Each has pros and cons. That's why the authors of this report refer to OpenFMB as an "integration framework." OpenFMB today is not fully defined, it's more of an approach to integrating new devices in the field and avoid stranded assets. In the vernacular, OpenFMB is a sort of "grab bag," loose framework that requires choices of protocols. One cannot implement two OpenFMB devices and assume that they will interoperate.

That's just at the protocol layer. At the application layer, OpenFMB does not yet strictly define all messages. When OpenFMB is implemented, the nature of messages must be defined as well. So trade-offs exist at the application layer as well. Therefore, aspects of OpenFMB remain undefined for now. If one utility uses OpenFMB for a new purpose, e.g., synchrophasors, one utility might define it one way, and another utility might define it another way. And the two systems would not interoperate and communicate. So interoperability gaps remain, depending on how OpenFMB is implemented. OpenFMB is more a process for how users can define messages rather defining them itself.

This undefined aspect of OpenFMB makes it difficult for it to reach commercial availability, because if Vendor A's messages are defined one way and Vendor B's messages are defined in another way, the two will not interoperate and communicate. Thus there's still a lot of "optionality" to OpenFMB, thus at this point it remains more a guide than an interoperable standard. (In the parlance of the IEEE Standards Association, e.g., OpenFMB would be called a guide, not a standard.)

MQTT: one of two protocols explored in this project

MQTT or Message Queue Telemetry Transport, was first defined by IBM but is now the standard used both in OASIS, the Organization for the Advancement of Structured Information Standards and in ISO/IEC, the International Organization for Standardization/International Electrotechnical Commission. MQTT is one of two protocols used in the demonstration project. MQTT defines the application layer protocol that runs on top of TCP/IP. So it is built on Internet technologies. For security, it uses Transport Layer Security (TLS), another Internet standard. Like http, MQTT runs on TCP/IP, and uses TLS for security.

MQTT's primary design is aimed at being "lightweight," i.e., targeted at IoT-type applications that favor small, inexpensive devices. It is designed to be lightweight both in terms of implementation – it uses minimal coding and, therefore, programming effort – as well as requiring low bandwidth from network resources. So it's fast and lightweight, which also means it has few features. That's thought of as its main advantage. Its disadvantage, according to some, is that it uses a broker and, therefore, it has a single point of failure.

DDS: the other protocol explored in this demo

DDS stands for data distribution service. It is another pub/sub protocol allowed under OpenFMB, and is one of the two protocols tested in the demonstration project. In terms of history and status, it has had mainly military applications, e.g., in equipment communicating with one another aboard submarines. Today DDS is an OMG – Object Management Group – standard. (OMG is an international, open membership, not-for-profit technology standards consortium.) At this point, DDS has a handful of implementations or use cases and is not as widely adopted as MQTT or AMQP (Advanced Message Queueing Protocol, described in the next section). There's active interest in DDS' potential, but it's fair to say that DDS is more in its infancy than other protocols identified under OpenFMB.

DDS is brokerless, in contrast to MQTT. That's viewed as one of its key advantages, i.e., it has no single point of failure. But that means paying attention to routing, discovery, etc., which affects scalability. One would not use DDS for a field network of thousands or millions of devices, thus it is not IoT friendly because it has a high overhead of programming. It is referred to as a "data-centric" protocol, meaning how a programmer would approach using it. Like other pub/sub protocols, the programmer doesn't think about the devices that are talking to each other, rather, the focus is on the nature of the data being published or subscribed to.

DDS does not run on TCP/IP. It can run on IP, but it has its own technology above IP. It doesn't use TCP, it doesn't use TLS – the traditional Internet protocols. For security it has its own, referred to as "DDS security." In a sense, DDS lives in its own world. It has a constituency as well as detractors.

Among its advantages is that it is brokerless, therefore faster. Again, no single point of failure. In the power utility world, where applications demand that lots of data is exchanged in real-time, or closed-loop control is needed (e.g., sample-value type data or synchophasors), DDS might be a candidate – those applications are its sweet spot. The corollary to the speed and lack of a single point of failure in brokerless protocols is, again, that discovery and security functions must be programmed into all the field devices communicating directly with one another. Also, without a broker, lots of pub/sub devices and their exchanges can overwhelm the network.

AMQP: not tested in this demo

The third protocol defined under the OpenFMB guidance is AMQP, or Advanced Message Queueing Protocol. It is built on TCP/IP and and it uses TLS for security – typical Internet protocols. AMQP is OASIS and ISO/IEC compliant standard. AMQP and MQTT are very similar: both are built on typical Internet protocols, are OASIS and ISO/IEC standards and both use brokers. The generally accepted difference between the two is that AMQP is richer, in that it provides more functionality. AMQP, for instance, can use both a pub/sub and a client-server communication approach. However, that added functionality comes at a cost. It is more complex, requires more programming and code and, therefore, is more difficult to implement. In sum, AMQP is richer and MQTT is more lightweight.

R-GOOSE Overview (Additional protocol reviewed in the project)

The Generic Object Oriented Substation Event (GOOSE) is a transport profile for IEC 61850. This profile was developed with the specific goal of performance in mind. As such, GOOSE only operates via Layer 2 addressing and supports multicast and quality of service. However, in the course of identifying new use cases for the IEC 61850 standard, the issue of transmitting data from one publisher to multiple subscribers in a network drove the development of routable multicast messages now known as Routable GOOSE (R-GOOSE). The primary additions being the use of routable IP addressing and a complete security profile.

2.3 Test System

The test system developed for this project was designed to meet the project's objectives and demonstrate the range of benefits of OpenFMB. This test system was designed to mimic two feeders on SDG&E's production distribution network, shown in Figure 1 and Figure 2. Figure 3 then illustrates the architecture of the test system, designed to mimic those two feeders, as described in more detail below.

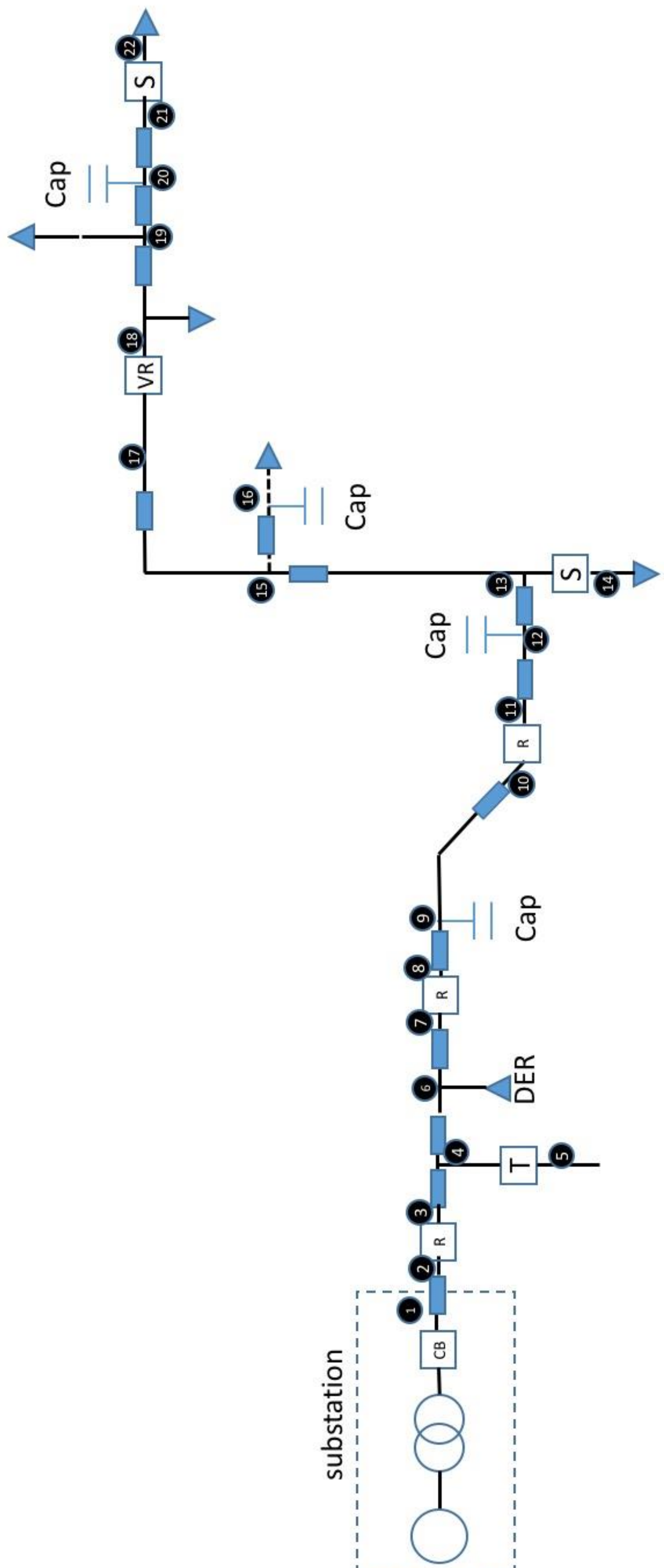


Figure 1 - SDG&E Feeder A

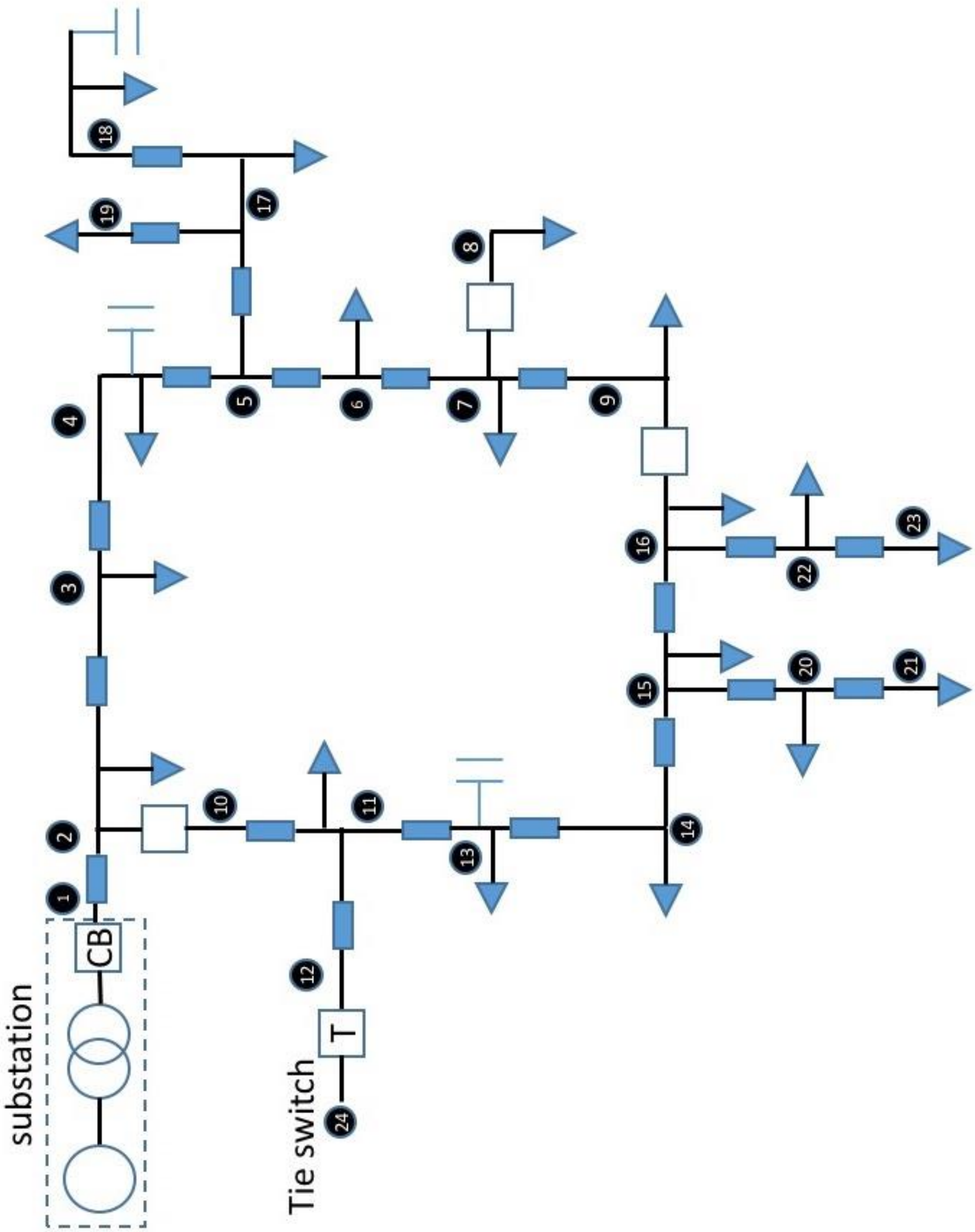


Figure 2 - SDG&E Feeder B

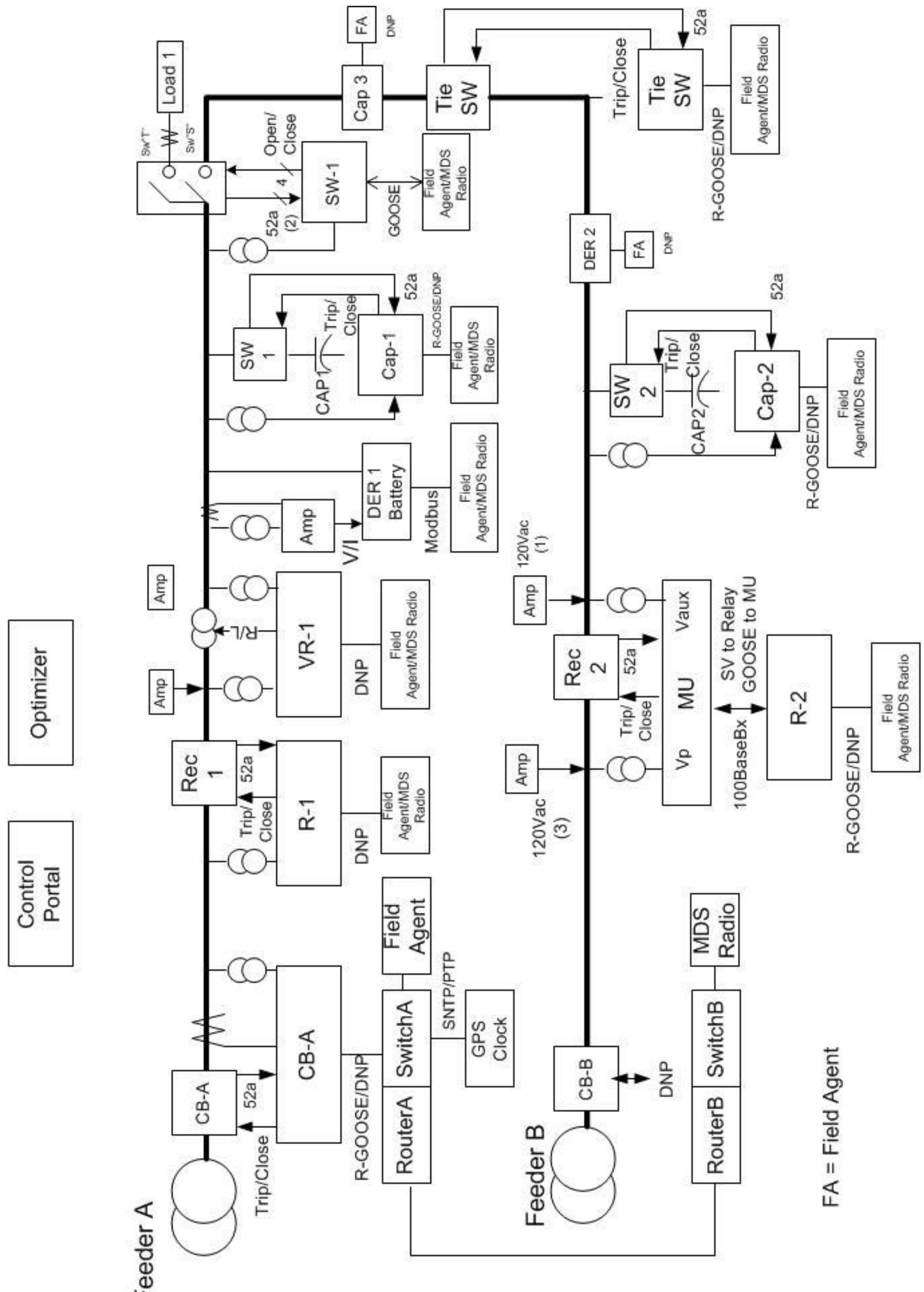


Figure 3 - Demonstration Architecture

A number of devices and simulators were used in the creation of the test system. These devices were selected to demonstrate interoperability amongst devices from a variety of manufacturers, each requiring an OpenFMB adapter to translate from their legacy communications technology to OpenFMB. These devices and simulators are listed in Table 2. Figure 4, Figure 5, and Figure 6 show the developed test system on racks, including labels for each device. These racks were then installed in the SDG&E ITF.

Table 2 - Devices and Simulators Used in Test System

Device Type	***Device Role***	***Device Description***
Control Portal	System, application	Application that provides a User Interface to visualize the circuit network, display measurement values and provide limited control capability for network devices.
Optimizer	System, application	Application which optimizes the resources included in the Vol/Var Use Cases. Optimization is accomplished using defined business rules.
Field Agent	device	Field agent software and hardware device that communicates with the "edge" field devices. The Field Agents includes Ethernet communications capability. FA nodes are connected to each Field Device and connected to the OpenFMB.
Breaker Relay	device	The Breaker Relay feeder protection system provides feeder protection, control, monitoring, and metering in an integrated package. Communicates via R-GOOSE and DNP.
Capacitor	device	The Capacitor Relay provides protection functions designed specifically to protect shunt capacitor banks. Protocols: R-GOOSE and DNP
Tie Switch	device	The controller system is a device designed to act as Tie Switch to demonstrate Use Cases. Protocol: R-GOOSE and DNP
Recloser Relay	device	The Recloser Control offers protection and communications capabilities for Automatic Network Reconfiguration in the event of a fault. Recloser-A with DNP protocol.
Voltage Regulator	device	The Voltage Regulator Controller to optimize System Voltage and control system voltage with DNP protocol.
Switch (2 position)	device	The load simulation relay provides three-phase restraint current inputs. 2 Position Switch with DNP protocol
DER / Battery Inverter	device	Inverter that connects battery to the VVC System. Assumed to be capable of operation as a rectifier. Controllable up in range zero to current maximum capability of battery. Uses Modbus protocol.
Flexible Load	device	Controllable load to simulate Critical customer loads; both shedable and non-shedable components.

Device Type	*Device Role*	*Device Description*
RTDS	System, application	Power system simulation software
Router Subnet A and B	Communication Device	Routes network traffic from Subnet A to Subnet B and vice-versa
900 MHz Radios	Communication Device	Long-range 900MHz radio access points. Configured to bridge Ethernet data over the radio link to the feeder remotes. Configured for 500kbps raw over-the-air data rate. Also configured to be a Wi-Fi access point for computer connections to the OFMB test rack.
Time Server	Server	Time server for the entire rack (both Feeder A and Feeder B). SNTP and PTP server.
Computer	Computer HW	R-GOOSE to OPC Adaptor (Windows Server)
HMI Display	System, application	Traditional HMI for Grid Devices
DER Inverter	Device	Energy Storage System device technology

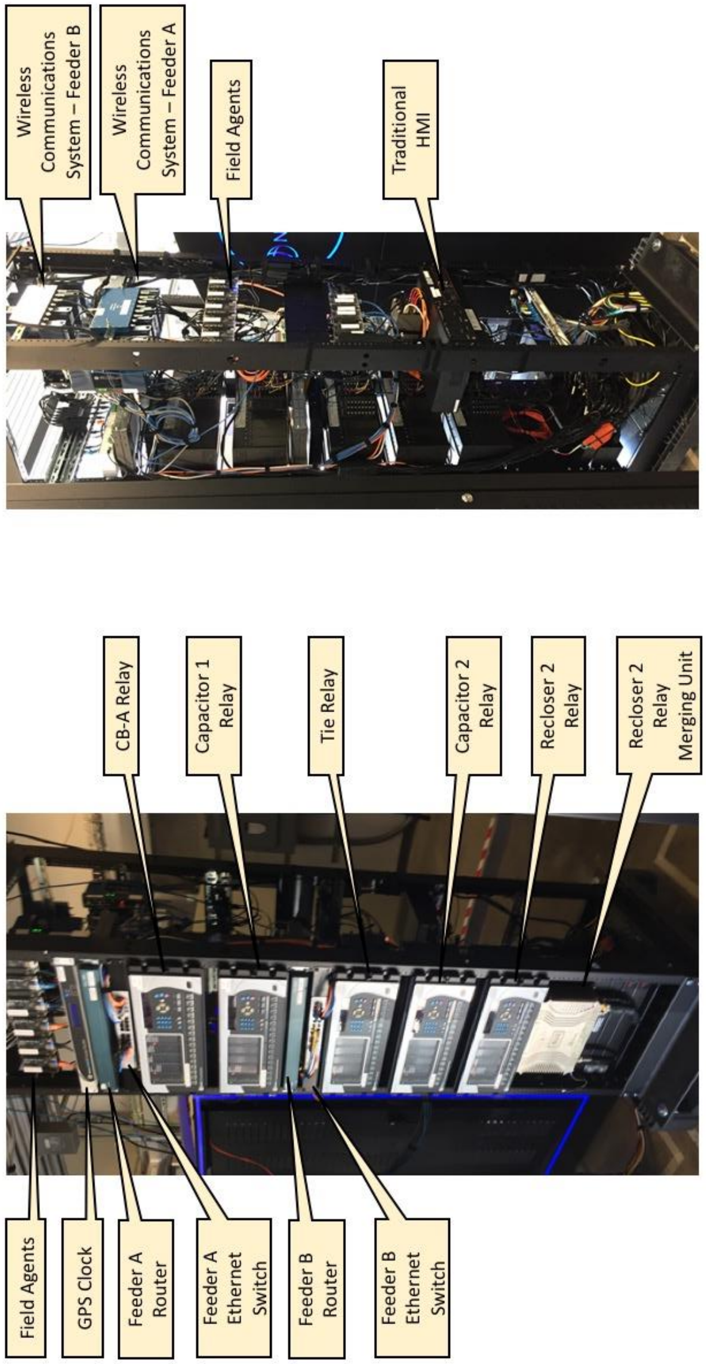
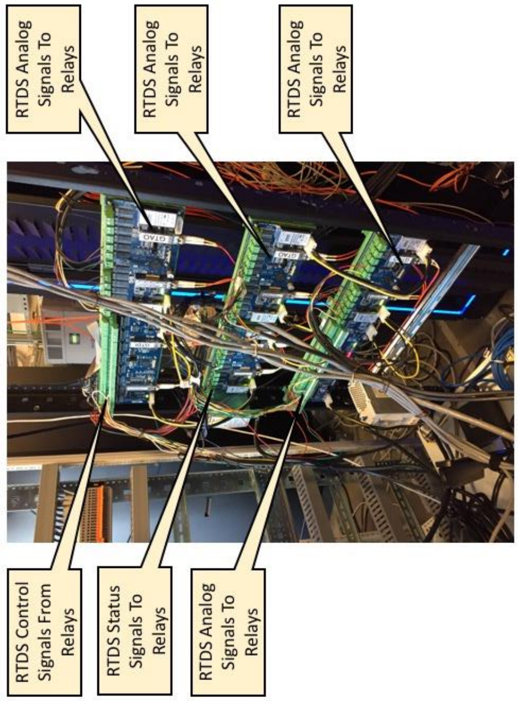


Figure 4 - Test System, Rack 1



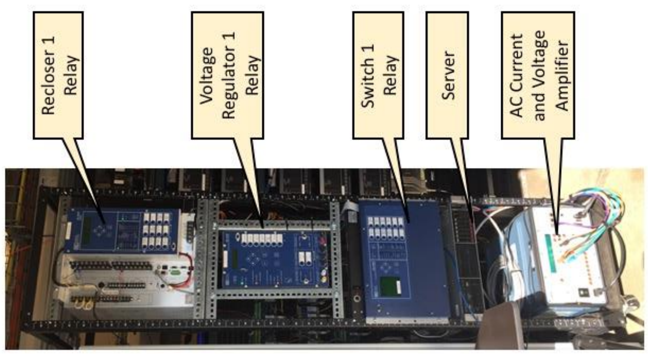


Figure 5 - Test System, Rack 2

Figure 6 - Test System, Rack 3

These devices were networked in such a way to mimic their location on two different feeders, “Feeder A” and “Feeder B,” using different networking technologies to mimic a realistic network design. The overall design of the communications is shown in Figure 7.

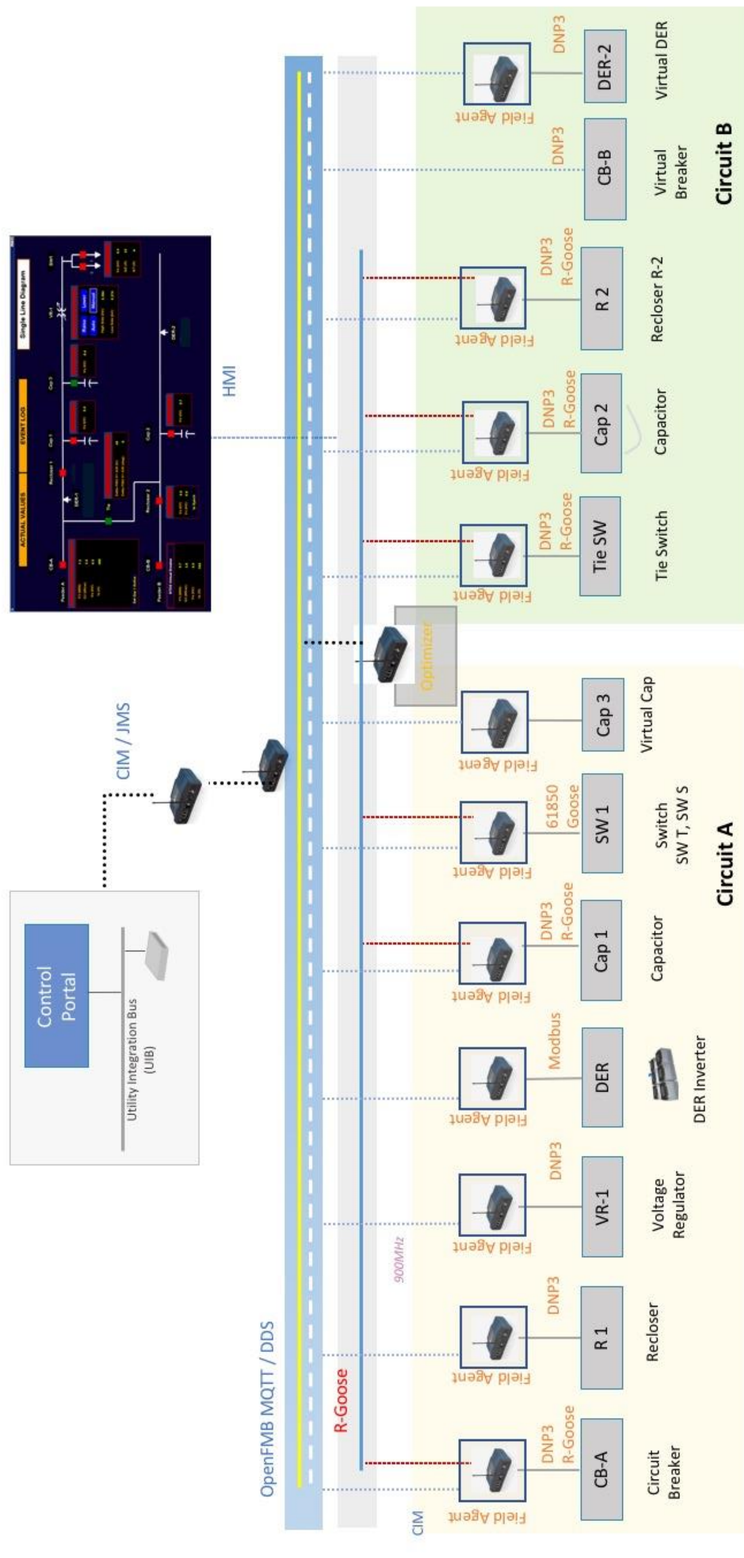


Figure 7 - Demonstration Communications Architecture

“Substation Devices” are connected via Ethernet cables to the Router/Switch for each feeder. These devices experience high speed networking connections between each other (10/100/1000Mbps). “Remote Devices” are connected via the 900MHz radio network. These devices in the real world would be located up to 10 miles from the substation and therefore, need long range wireless to communicate. Each feeder has a 900MHz radio access point and therefore the devices on that feeder share the 500kbps link.

The networking is such that Feeder A and Feeder B are in two different subnets, but connected by routers. That is, the two feeders are connected at Layer3. The OpenFMB rack IP addressing scheme is as follows (the actual IP addresses have been redacted throughout this report and replaced with ‘x’):

- Feeder A is in the xxx.xxx.42.x subnet
- Feeder B is in the xxx.xxx.43.x subnet

For connecting computers and tablets to run tests and/or troubleshoot, the OpenFMB rack contains a Wi-Fi Access Point and DHCP Server for ease of use.

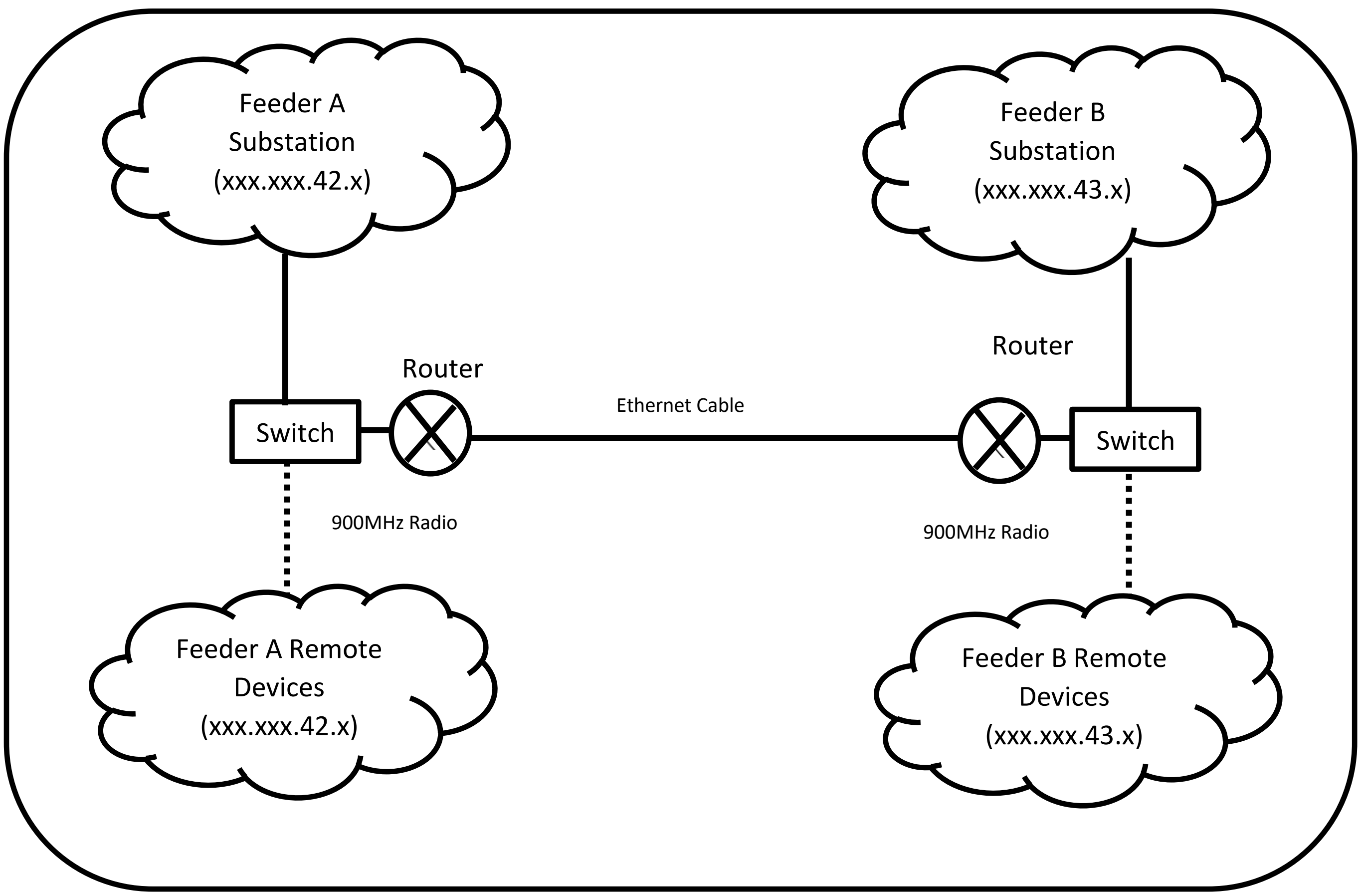


Figure 8 - High-Level Network Concept

As shown in Figure 8, the test system network is designed to connect every device in two feeders. The devices and computers in the substation are connected via high-speed Ethernet over copper cable. The remote devices of each feeder are connected via a high-power/long range radio link. The two feeders are connected to each other through 2 routers. In this way, the test system network is comprised of four major sub-sections:

1) Feeder A Substation Sub-Network
2) Feeder A Remote Devices Sub-Network
3) Feeder B Substation Sub-Network
4) Feeder B Remote Devices Sub-Network

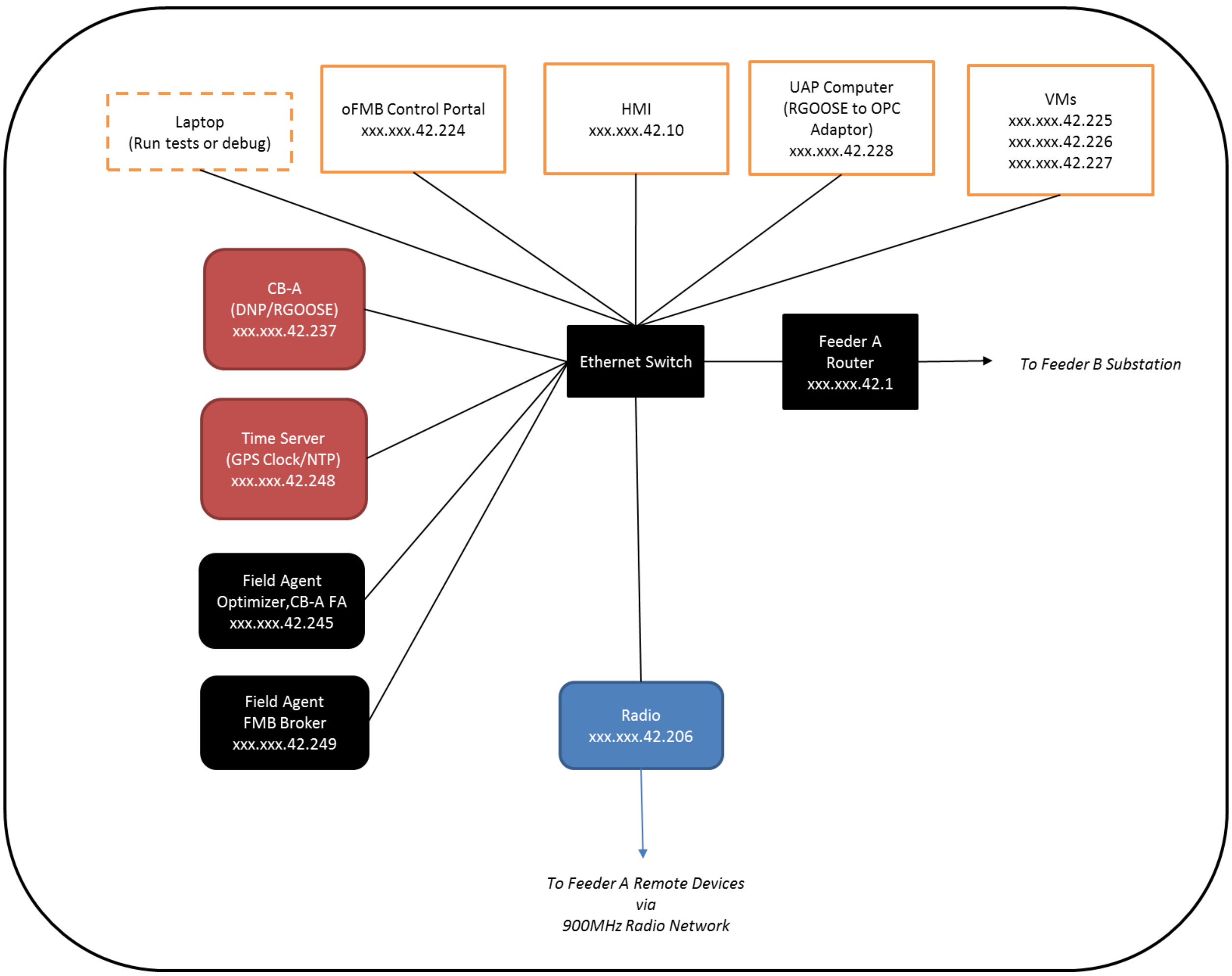


Figure 9 - Feeder A Substation Network

As shown in Figure 9, the "Feeder A Substation" portion of the network contains devices that would normally be connected in an electrical substation or be connected by a high-speed network connection to the substation. The Feeder A substation contains both devices and computers. Everything in this subnet is connected through the use of an Ethernet switch using copper cables

(Cat5/6). In this way, all devices communicate using IP (Internet Protocol) over 10/100/1000BaseT Ethernet.

There are several computers and virtual machines (VMs) connected to this part of the network. The OpenFMB Control Portal provides visualization of the FMB data. The HMI machine talks legacy protocols and shows the user details regarding the devices further down Feeder A. The UAP machine provides RGOOSE to OPC translation. An engineer's laptop can be connected to the switch to provide troubleshooting access or to run tests.

A time server that acts as a NTP server for the entire network is in this portion of the network. Devices learn date and time of day from this device. This ensures all devices in the network share the same time of day, which is important for correlating logs and published data. The circuit breaker controller (CB-A) is also connected to this portion of the network.

There are two field agents at the substation of Feeder A. In general, field agents can be loaded with different applications to provide intelligence and data translation at the edge of the network. In this case, we have two field agents configured to provide very specific functionality. One field agent functions as the optimizer for the feeder. The other field agent acts as the Field Message Bus Broker ("FMB Broker"). The FMB Broker routes messages to/from other field agents in the network. This function is how field agents can participate in different FMB topics (logical data streams).

There are two devices in the Feeder A Substation network that act to route data to other parts of the network. The Feeder A Router connects Feeder A to Feeder B so that the two feeders can send data back and forth. This router must be capable of routing both unicast and multicast IP traffic. The Radio Access Point (AP) connects wirelessly to other radios further down the feeder. The Radio AP creates a point-to-multipoint (star) network that connects all the remote radios. In this way, every remote radio transmits directly with the AP while the AP maintains multiple connections – one to each remote radio. The radio signals in the test network are carried by RF cables with fixed attenuation. In the real world, these signals would travel through antennas and then over-the-air for large distances (1-10 miles) to connect the remote devices of feeder A to the substation of feeder A.

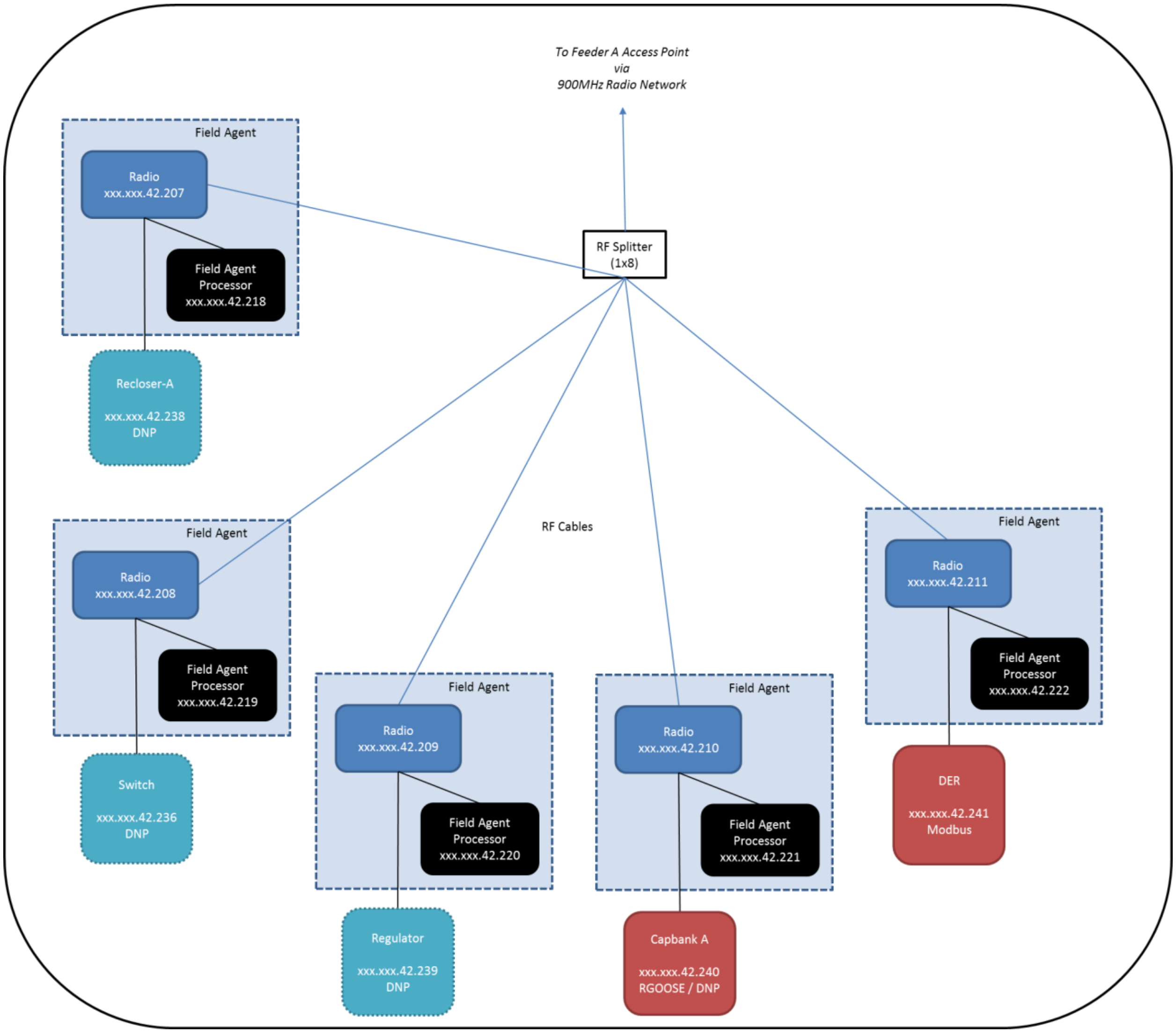


Figure 10 - Feeder A Remote Devices

As shown in Figure 10, there are a number of remote devices connected to Feeder A, along with their respective field agents.

Each controllable utility distribution system device is connected to the network using a wireless field agent. The wireless field agent contains a high-power/long range radio to connect remote devices that may be miles away from the substation. The field agent also has copper Ethernet and serial ports to physically connect to the electrical grid remote devices. Each field agent can run different field message bus protocols (MQTT, DDS, RGOOSE transport, etc.). The field agents are also capable of being loaded with different applications to implement edge features and device protocol translation (Modbus, DNP3, etc.) Therefore, we can connect different types of devices talking different protocols to the same network.

This OpenFMB test network contains various utility distribution system devices. We have the following in Feeder A:

1) Recloser controller running DNP3 ("Recloser-A")

2) 4 Position Switch controller running DNP3 ("Switch")

3) Regulator running DNP3 ("Regulator")

4) Capacitor Bank Controller running RGOOSE and DNP3 ("Capbank A")

5) Battery Inverter running Modbus ("DER")

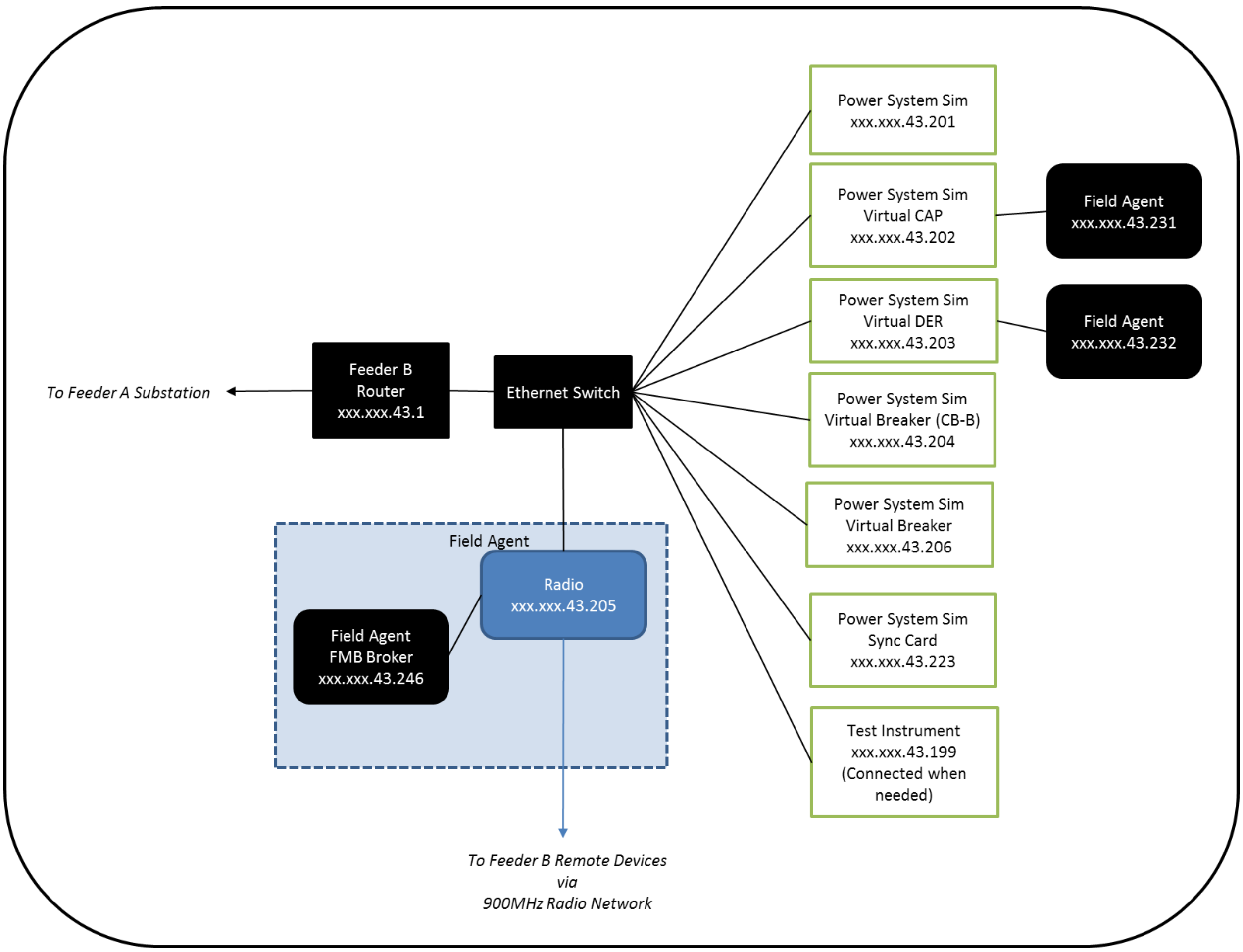


Figure 11 - Feeder B Substation Network

As shown in Figure 11, the "Feeder B Substation" portion of the network contains devices that would normally be connected in an electrical substation or be connected by a high-speed network connection to the substation. The Feeder B substation contains both devices and computers. Everything in this subnet is connected through the use of an Ethernet switch using copper cables (Cat5/6). So, in this way, all devices communicate using IP (Internet Protocol) over 10/100/1000BaseT Ethernet.

An electrical grid simulation system is connected to the network at the Feeder B Substation level. The simulation system is comprised of both physical and virtual network elements. The main simulator hardware and its synchronization card are physical devices at this level. The simulation system is also configured for a number of virtual devices. These include a virtual capacitor controller, a virtual DER controller, and two virtual breaker controllers.

There are three field agents at the substation of Feeder A. In general, field agents can be loaded with different applications to provide intelligence and data translation at the edge of the network. One field agent acts as the Field Message Bus Broker ("FMB Broker"). The FMB Broker routes messages to/from other field agents in the network. This function is how field agents can participate in different FMB topics (logical data streams). The other two field agents provide data translation and control for the virtual CAP and the virtual DER.

There are two devices in the Feeder A Substation network that act to route data to other parts of the network. The Feeder B Router connects Feeder B to Feeder A so that the two feeders can send data back and forth. This router must be capable of routing both unicast and multicast IP traffic. The Radio Access Point (AP) connects wirelessly to other radios further down the feeder. The Radio AP creates a point-to-multipoint (star) network that connects all the remote radios. In this way, every remote radio transmits directly with the AP while the AP maintains multiple connections – one to each remote radio. The radio signals in the test network are carried by RF cables with fixed attenuation. In the real world, these signals would travel through antennas and then over-the-air for large distances (1-10 miles) to connect the remote devices of feeder B to the substation of feeder B.

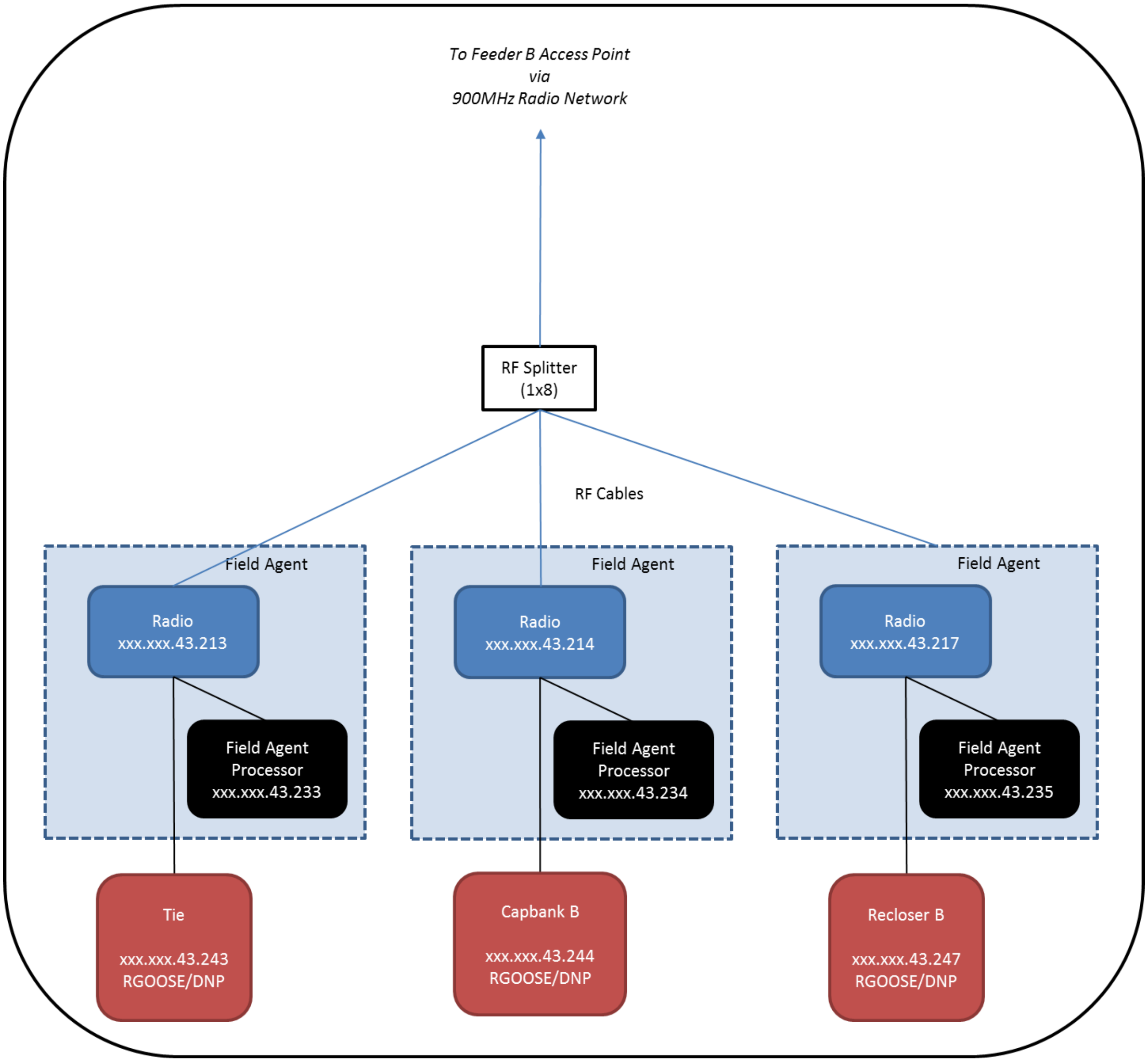


Figure 12 - Feeder B Remote Devices

As shown in Figure 12, there are a number of remote devices connected to Feeder B, along with their respective field agents.

Each controllable utility distribution system device is connected to the network using a wireless field agent. The wireless field agent contains a high-power/long range radio to connect remote devices that may be miles away from the substation. The field agent also has copper Ethernet and serial ports to physically connect to the electrical grid remote devices. Each field agent can run different field message bus protocols (MQTT, DDS, RGOOSE transport, etc.). The field agents are also capable of being loaded with different applications to implement edge features and device protocol translation (Modbus, DNP3, etc.) Therefore, we can connect different types of devices talking different protocols to the same network.

This OpenFMB test network contains various utility distribution system devices. We have the following in Feeder B:

1) Tie controller running RGOOSE and DNP3 ("Tie")

2) Capacitor Bank Controller running RGOOSE and DNP3 ("Capbank B")

3) Recloser controller running DNP3 ("Recloser B")

2.4 Summary of Use Cases

Table 3 shows the use cases that were developed for demonstration on the test system. For more details of the use cases, see 0.

Table 3 - Summary of Use Cases

Use Case 1a: OpenFMB Connection to Vendor B Devices and Virtual DER / Cap Bank	
Objective:	The objective was to demonstrate the use of OpenFMB to communicate from a Control Portal to a field device showing status (measurement values) and control (change status).
Description:	An operation of Recloser 1 (Open/Close) and Voltage measurements was made through OpenFMB messaging to the VENDOR B RECLOSER 1. The control and status of the 2-feeder switch was demonstrated from the Control Portal through OpenFMB to the VENDOR B Switch. The control and status of the Virtual DER and Virtual Cap Bank were also exercised.
Use Case 2a: Var Control	
Objective:	The objective was to evaluate R-GOOSE as an alternative pub/sub protocol under the OpenFMB standard / framework.
Description:	An operation of Recloser 1 (Open/Close) and Voltage measurements was made through OpenFMB messaging to the VENDOR B RECLOSER 1. The control and status of the 2-feeder switch was demonstrated from the Control Portal through OpenFMB to the VENDOR B Switch. The control and status of the Virtual DER and Virtual Cap Bank were also exercised.
Use Case 2b: Man-in-the-Middle Augmented Voltage/Var Control	
Objective:	The objective was to demonstrate manual control and operation using OpenFMB.
Description:	Capacitor 1 was closed. When, after closing Capacitor 1, the var level was set above the setting threshold in the VENDOR A CB-A, an OpenFMB alarm of "over VAR" was issued by the VENDOR A CB-A relay. This alarm was received by the Control Portal and indicated. The operator then placed VR1 in auto mode.
Use Case 2c: Peer-to-Peer Voltage/Var Control	
Objective:	The objective of Use Case 2c was to demonstrate automated control or operation using OpenFMB.
Description:	Capacitor 1 was closed. When, after closing Capacitor 1, the var level was set above the setting threshold in the VENDOR A CB-A, an alarm of "over VAR" was issued by the VENDOR A CB-A. This alarm was received by the Optimizer and the Optimizer then placed VR 1 Voltage Regulator in auto mode via an DNP OpenFMB command.
Use Case 2d: Voltage Override	
Objective:	The objective of Use Case 2d was to demonstrate the communication of the rejection of manual control and subsequent automatic response based on prevailing local condition using OpenFMB.

Description:	The Control Portal sent a close command to VENDOR A CAPBANK 1. As the voltage on VENDOR A CAPBANK 1 was set using the simulator to be too high, VENDOR A CAPBANK 1 refused the CLOSE control and sent a message to the VENDOR A CB-A indicating refusal to execute the requested close action. An OpenFMB message was issued indicating such from VENDOR A CB-A and was displayed on the Control Portal. Detection of Over-Voltage was also transmitted to the Optimizer which then cause VR1 to change to auto mode.
Use Case 3a: Inter-network Var Control	
Objective:	The objective of this use case was to demonstrate the inter-network communication capability of OpenFMB.
Description:	Building on Use Cases 2a, b, c, and d, an OpenFMB command was issued from the Control Portal to open Recloser 2 and then close the TIE switch. The status of Recloser 2 and Tie Breaker were monitored by the Recloser 2 and Tie Switch, respectively. This information was then sent inter-network via R-GOOSE to VENDOR A CB-A. The var load on the feeder was then increased above the setting threshold. The VENDOR A CB-A then made a determination to close Capacitor 2 for additional var support.
Use Case 3b: Peer-to-Peer Volt/Var Control	
Objective:	The objective of this use case was to demonstrate the peer-to-peer communication capability of OpenFMB to achieve progressive var support.
Description:	The var load on the feeder was increased above the setting threshold. VENDOR A CB-A then issued a signal (High Var) to the Optimizer that additional var support was needed. Upon receipt of the High Var message, the Optimizer then switched the Voltage Regulator to manual mode.
Use Case 4a: DER Active Power Control	
Objective:	The objective of this use case was to demonstrate the ability of OpenFMB to bridge Modbus communication, and to demonstrate the interoperation of traditional IED's and DER using OpenFMB.
Description:	A start command was sent from the Control Portal to the DER. An OpenFMB command to change the Power level was issued. In addition to changing the Var/Power order, a command was issued to change between operational modes from Voltage Droop regulation mode to Volt/Watt Mode regulation mode. A heartbeat signal was removed by disconnecting the DER from the network and the response of the inverter was noted. After removing the heartbeat, communication was reestablished and a reset command was issued to DER. Breaker A was opened and the response of the DER was recorded.
Use Case 5a: DER on-line / off-line	
Objective:	The objective of this use case was to demonstrate the use of R-GOOSE to improve system performance by communicating breaker status to a DER and thereby over-riding autonomous DER control functions.
Description:	A button push on VENDOR A CB-A was used to open CB-A. Upon detection of CB-A open, CB-A sent a command to VENDOR A CAPBANK 1. VENDOR A CAPBANK 1 operated an output contact to take the DER off-line.

Use Case 6a: Enhanced Automatic Feeder re-deployment	
Objective:	The objective of this use case was to demonstrate the mapping of data from GOOSE messages into OpenFMB as well as complex inter-device communication.
Description:	Using the HMI, CB-B was tripped. Vendor A CB-A Phase A current was then set to pass its pre-programmed threshold. As a result, Vendor A CB-A set its “Healthy Feeder” based on the threshold conditions, enabling auto re-deployment. As R-2 was monitoring the “Healthy Feeder” status, it issues a trip command to open R-2. R-2 then sends a command to close T-1 via R-GOOSE. Finally, Vendor A CB-A detected that T1 closed and changed its setting group and visualized via the HMI.
Use Case 7a: Automatic Feeder Re-Close	
Objective:	The objective of this use case was to demonstrate circuit re-configuration back to normal operating condition.
Description:	CB-B was closed by the HMI, placing voltage on the Breaker side of Recloser 2. Voltage was then detected on both sides of Recloser 2 and the phase angle of the voltage across the recloser was less than 30 degrees (as measured by R-2). As a result, Recloser 2 sent an open command to T-1. VENDOR A CB-A identified T-1 opened and changed back to the setting group 1.
Use Case 8a: Sample Value Test Cases (documentation only)	
Objective:	The objective of this use case was to demonstrate the high-speed transmission of sample values to further develop communication requirements for OpenFMB.
Description:	The measurement and transmission of voltage and current values from field equipment are known as sample values (SV). SV typically require high sample rates in the range of 3,000 to 96,000 samples per second. Additionally, the device creating the samples (known as the Merging Unit) can be located several kilometers away. IEC 61850 introduced the concept of sample values as a digital interface to optical current and voltage sensors as well as application-specific circumstances where remote location of voltage and current sensors is required/desirable. The IEC 61850 standard addresses issues such as data synchronization and phase correction. Given the high bandwidth and low latency constraints of such data, further study of its applicability to OpenFMB is needed.
Use Case 8b: Synchrophasors via R-GOOSE	
Objective:	The objective of this use case was to demonstrate the use of pub/sub technologies to transmit high speed data (e.g. synchrophasors) via routable R-GOOSE and evaluate the incorporation into OpenFMB standards.
Description:	Synchrophasors (V1 Magnitude and Angle) were mapped into Generic Analog 61850 data objects in VENDOR A CB-A and Recloser 2 and then included in R-GOOSE messages. R-GOOSE reception by T-1 was monitored by changing the source voltage angle and magnitude between Feeder A and Feeder B.
Use Case 9a: Dynamic Subscription (documentation only)	
Objective:	The objective of this use case was to identify the requirement for dynamic subscription for all messaging protocols for incorporation into OpenFMB

	standards.
Description:	In the scenario, when Feeder A and Feeder B are separated, there is no need to share messages between them. Once the T-1 is closed, it becomes desirable for the devices on Feeder A to be able to “subscribe” to information from devices on the “extended” line. For that purpose, it should be noted that Dynamic Subscription becomes a need in this test case. Additionally, the definition of the data objects from the newly subscribed devices may be needed, especially if there have been setting changes in any of the newly-subscribed devices.
Use Case 10a: End-to-End Security (documentation only)	
Objective:	The objective of this use case was to identify the requirement for end-to-end security in OpenFMB standards.
Description:	When communicating device-to-device in the field, end-to-end secure communications are required. End-to-end security should be developed that addresses authentication, authorization, access control, confidentiality, integrity, non-repudiation, availability, and accountability.
Use Case 11a: File transfer	
Objective:	The objective of this use case is to demonstrate file transfer using OpenFMB.
Description:	To demonstrate the transfer of a settings file, a file was transferred from the Administration Node to a Field Agent (OpenFMB Adapter). This file was of a size representative of a settings file, ~10 KB. It should be noted that settings files may also be unique to each OpenFMB node.
Use Case 11b: Firmware	
Objective:	The objective of this use case was to document or demonstrate firmware transfer.
Description:	To demonstrate the transfer of a firmware image, a file was transferred from the Administration Node to a Field Agent (OpenFMB Adapter). This file was of a size representative of a firmware image, ~10 MB. It should be noted that firmware images have various security characteristics that may be unique to each firmware instance, such as manufacturer signing. Firmware images may also be unique to each OpenFMB node.
Use Case 11c: Provisioning (documentation only)	
Objective:	The objective of this use case was to document the requirement to provision field devices using OpenFMB.
Description:	To set up an OpenFMB network, the secure provisioning of OpenFMB nodes is critical. Each OpenFMB node has to have its security credentials verified with the Administration Node. Various settings also need to be communicated relating to both the node’s network and the node’s application functionality. Initial subscriptions to other OpenFMB nodes also need to be created.
Use Case 12a: File transfer	
Objective:	The objective of this use case was to demonstrate file transfer using OpenFMB.
Description:	File transfer from an Administration Node to other nodes through OpenFMB (MQTT) was demonstrated. Currently, OpenFMB does not specifically define

	file transfer. In the future, OpenFMB may choose to use another protocol better suited for file transfer (e.g., SFTP) as pub/sub protocols are not typically used for large, point-to-point, file transfers. Further, individual settings and firmware are likely not to be broadcast as security images; configuration and other aspects are likely to be unique to each node. (Note: Refer to Use Case 11a for further information on file transfer.)
13a OpenFMB using DDS	
Objective:	The objective of this use case was to demonstrate OpenFMB using DDS
Description:	To demonstrate OpenFMB using DDS, the Tie SW is set as the one of the DDS nodes. The Tie SW gets the data (measurement value) from DNP3 adaptor and publishes the data on the DDS virtual FMB. Then another DDS node subscribes to the data. When the data is received, the data is published in the Audit Log.

2.5 System Tests

Table 4 summarizes the tests run on the demonstration system to verify the use cases. The complete test case document, including specific results, is provided in Appendix B.

Table 4 - System Tests

Use Case	Test Case Step	Description
1a: OpenFMB Connection to Vendor B Devices and Virtual DER / Cap Bank	1	Start control portal.
	2	Start field agents.
	3	Insert ALL Vendor A devices • CB-A, Recloser 2, Tie SW, Cap 1, Cap 2
	4	Monitor measurement values on R1.
	5	Control portal sends R1 Open command.
	6	Monitor measurement values on SW (Vendor B Switch).
	7	Control portal sends SW Open command.
	8	Monitor measurement values on Virtual DER.
	9	Control portal exercises range of DER commands: • Reset • Set voltage source inverter – PQ Mode • Set for Voltage / Watt mode of operation • Initial real power set point • Initial reactive power set point
	10	Monitor measurement values on Virtual Cap Bank.
	11	Control portal sends control values to Virtual Cap Bank.
2a: Var Control	1	Start control portal.
	2	Start field agents / optimizer.
	3	Measure the vars at the breaker Feeder A (Vendor A CB-A).
	4	Change vars in the RTDS model to exceed a set point.
	5	Send R-GOOSE message from Vendor A CB-A to Vendor A Cap Bank 1 to close capacitor Vendor A Cap Bank 1.
	6	Sent R-GOOSE message received by Vendor A Cap Bank 1 capacitor.
	7	Measure the vars at the breaker Feeder A (Vendor A CB-A).
2b: Man-in-the-Middle Augmented Voltage/Var Control	1	Measure the vars at the breaker Feeder A (Vendor A CB-A).
	2	Change vars in the RTDS model to exceed a set point if needed.
	3	Vendor A CB-A sends an alarm of “Over VAR.”
	4	Control portal receives alarm.
	5	Operator places VR1 in Auto mode.
2c: Peer-to-Peer Voltage/Var Control	1	Measure the vars at the breaker Feeder A (Vendor A CB-A).
	2	Change vars to exceed a set point.
	3	Vendor A CB-A sends an alarm of “Over VAR.”
	4	Control portal and optimizer receive alarm.

Use Case	Test Case Step	Description
	5	Optimizer sends command to VR1 to switch to Manual mode.
	6	VR1 regulates to a previously issued set point in Manual mode.
	7	Measure the vars at the breaker Feeder A (Vendor A CB-A).
2d: Voltage Override	1	Monitor voltage on Cap 1 Vendor A Cap Bank 1.
	2	RTDS simulates an increase in voltage (high voltage) on Cap 1 Vendor A Cap Bank 1.
	3	Control portal sends close command to Vendor A Cap Bank 1.
	4	Cap 1 Vendor A Cap Bank 1 refuses the close control.
	5	Cap 1 Vendor A Cap Bank 1 sends message to CB-A indicating refusal.
	6	CB-A sends message “Over-Voltage” to optimizer.
	7	Optimizer sends message to VR1 to change to Auto mode.
	8	VR1 receives Auto mode command.
3a: Inter-network Var Control	1	Start control portal.
	2	Start field agents.
	3	Control portal sends Open command to R2.
	4	Control portal sends Close command to T1.
	5	R2 monitors device status.
	6	T1 monitors device status.
	7	Var load on the feeder is increased above the setting threshold.
	8	Vendor A CB-A monitors network and determines to close Cap 2.
	9	Vendor A CB-A closes Cap 2 (R-GOOSE).
	10	Control portal displays measurement values.
3b: Peer-to-Peer Volt/Var Control	1	Var load on the feeder is increased above the setting threshold.
	2	Vendor A CB-A monitors network and determines var is above threshold.
	3	Vendor A CB-A issues a signal (High Var) to optimizer for var support.
	4	Optimizer receives message.
	5	Optimizer sends command to VR1 to switch to Manual mode.
	6	Control portal displays measurement values.
4a: DER Active Power Control	1	Start control portal.
	2	Start field agents.
	3	Operator issues a start command via the control portal.

Use Case	Test Case Step	Description
	4	Operator issues an enable set point command.
	5	Operator issues Real Power setpoint
	6	Operator issues Reactive Power setpoint
	7	DER mode changed to Volt / Watts mode.
	8	DER mode changed to Volt / Vars mode.
	9	Test engineer removes Ethernet connection to DER.
	10	Test engineer reconnects Ethernet connection to DER.
	11	Operator issues reset command to DER via control portal.
	12	Operator opens Breaker A.
5a: DER Online / Offline	1	Pushbutton command on Vendor A CB-A to open CB-A.
	2	Vendor A CB-A de-energizes Feeder A.
	3	Upon detection of Breaker A open, Vendor A CB-A sends a command to Vendor A Cap Bank 1.
	4	Vendor A Cap Bank 1 operates an output contact to take the DER offline.
	5	DER operates and goes offline.
6a: Enhanced Automatic Feeder Re-Deployment	1	Start control portal.
	2	Start field agents.
	3	Test engineer trips CB-B from HMI.
	4	Vendor A Phase A Current < Threshold then the Healthy Circuit status issued
	5	Vendor A CB-A sets “Healthy Feeder event” based on threshold conditions.
	6	Vendor A CB-A auto re-deployment enabled (phase A current ≤ threshold).
	7	R2 monitors “Healthy Feeder A” voltage status.
	8	R2 issues trip command open R2.
	9	R2 sends command to close T1
	10	Vendor A CB-A detects T1 closed and changes settings group.
	11	Vendor CB-A Phase A Current > Threshold then the “Load Shed status issued
	12	Vendor A CB-A sends “Load Shed” DNP point via OpenFMB to OPC UA (UAP) to SW T
	13	Vendor A CB-A Phase A Voltage ≤ Threshold then the Healthy Circuit status issued
	14	Vendor A CB-A Commands Circuit A reconfiguration
	15	Vendor A CB-A detects Tie-Breaker T1 closed, change setting group
7a: Automatic Feeder Re-Close	1	Start control portal.
	2	Start field agents.

Use Case	Test Case Step	Description
	3	Close CB-B.
	4	Measure voltage (high and load side) of R2.
	5	Measure phase angle of R2. Note: RTDS can be used to adjust phase angle.
	6	Close R2.
	7	R2 sends Open command to T1.
	8	Vendor A CB-A monitors T1 is open and changes back to the original settings group (1).
	9	Control portal displays measurement values.
	10	Close CB-B.
	11	Measure voltage (high and load side) of R2.
	12	Measure phase angle of R2. Note: RTDS can be used to adjust phase angle.
	13	Close R2, R2 fails to close
8a: Sample Value		*Documentation Only*
8b: Synchrophasors via R-GOOSE	1	Vendor A CB-A and R2 send synchrophasor data.
	2	Change source voltage angle and magnitude between Feeder 1 and Feeder 2.
9a: Dynamic Subscription		*Documentation Only*
10a: End-to-End Security		*Documentation Only*
11a: File Transfer	1	Start control portal.
	2	Start optimizer.
	3	Control portal sends message to Vendor A CB-A optimizer.
11b: Firmware		*Documentation Only*
11c: Provisioning		*Documentation Only*
12a: Operational Data File Transfer using OpenFMB		*Documentation Only (See 11a)*
13a OpenFMB using DDS	1	Set Vendor A Tie SW as one of the DDS nodes
	2	Vendor A Tie SW (Node 1) receives data (DNP3 adaptor) and publishes data via DDS OpenFMB
	3	Node 2 subscribes to data from Node 1 (View Audit Log)

2.6 Data Collection

During testing, data was collected from the demonstration system in a variety of ways including network packet captures, oscillography, and sequence of events. This data was then analyzed to create the findings and recommendations given later in this report. Additionally, this data was used in the various test cases to confirm correct operation and validation of the functionality. Detailed use case descriptions are presented in Appendix A and detailed results of test cases are presented in Appendix B.

3 Overall Project Results

3.1 Technical Results and Findings

Many aspects of OpenFMB remain undefined. As each implementation of OpenFMB may define those aspects differently, there are likely interoperability issues between different OpenFMB implementations. For the purposes of this project, those aspects that had to be defined to create a fully functioning demonstration system included:

- Provisioning of devices
- Management services (e.g., time synchronization)
- Security
- Data profiles (e.g., OpenFMB says to use CIM, but without needed precision)
- Configuration
- Standardized adapters for data translation between protocols

Similarly, OpenFMB's optionality allows the use of multiple protocols, such as those tested during this project (i.e., MQTT, DDS). Currently, OpenFMB allows each implementation to select which protocols they believe best for their circumstances. However, as each implementation of OpenFMB may choose to use different protocols, there are, once again, likely to be interoperability issues between different OpenFMB implementations. Although this project tested multiple protocols, a production deployment would likely need to constrain itself to a single protocol for a given circumstance.

Each protocol tested in this project uses a multicast approach to discovery and the transfer of data, which resulted in a level of data traffic that adversely affected network performance, increasing latency and packet loss. In a real-world production system, the network would need to be designed to take that multicast traffic into account. A production deployment would also likely need to constrain itself to a single protocol for a given network.

This project's test system also used different networking technologies, including Ethernet and 900 MHz radio, which saw degraded system performance when multicast traffic was routed between those technologies. This degraded performance was a result of several factors including saturation of the network bandwidth and the inefficiencies of multicast traffic with radio technologies (where there is often not a channel dedicated to multicast traffic but rather multicast traffic must be repeated for each connected device).

In light of potential data traffic congestion, message prioritization, such as Quality of Service, is needed for OpenFMB so that critical messages are not impeded by, for instance, less urgent file transfers. Existing, legacy client/server and/or master/slave devices have limits on the number of other devices to which they can communicate, making them unfit for peer-to-peer uses. This points to the strengths of OpenFMB and R-GOOSE publish/subscribe messaging approaches; they are designed for peer-to-peer communication.

The OpenFMB payloads, the format for data being exchanged, used in this project proved inefficient and needs further exploration to improve efficiencies. Currently, the OpenFMB standard is silent on payload formats and further work is needed to determine or define optimally efficient payloads, such as payload compression and/or more efficient formats.

The use of deadbands to report exceptions in the recording of analog information from various devices in the network needs fine-tuning to take network constraints into account and limit exception reports. While this is not unique to OpenFMB, any use of OpenFMB in the future should take this need into account. Currently, configuring adapters and mapping is difficult, particularly when standards have optionality. The commercialization of OpenFMB-related systems would have to facilitate the mapping and integration of existing devices, particularly when multiple protocols and vendor implementations are involved. Standardization of mapping (e.g., a file format) would be useful. Such a standardized mapping could then be used during the configuration of a given adapter.

The use of adapters for protocol translation introduces additional latency. The availability of native OpenFMB devices that preclude the need for adapters could eliminate adapter-related latency. Such latency may prove detrimental in certain use cases such as closed-loop control, sample value data, and synchro phasor communication.

To achieve reliability in data transfer, each protocol uses different mechanisms. For example, MQTT uses TCP with acknowledgements; R-GOOSE uses message repeat. Further study may reveal the pros and cons of the various reliability mechanisms and their impact on overall communication system performance.

OpenFMB works today through the use of adapters, which allows access to all devices in a unified manner and could be useful to avoid stranded assets, integrate existing assets into IoT and enable peer-to-peer communication. This project was thus enabled to tie together a variety of devices produced by several vendors using different standards (e.g., IEC 61850, DNP3, Modbus). As noted, the benefits of adapters are constrained by the additional latency they produce.

By using adapters, OpenFMB provides all devices with a common data model. This makes it possible for utilities to use applications that aren’t necessarily tailored to a specific technology. Utilities are freed to use best-of-breed applications because there is a common application interface available.

Further study of the pros and cons of using a broker would be useful, as well as determining its role and placement in specific network and security-related designs. (MQTT uses a broker. DDS and R-GOOSE do not.)

Lastly, an additional finding of this project was the need for dynamic subscriptions and mechanisms to support their configuration. The dynamic subscription approach should be explored for use with OpenFMB as well as other technologies.

3.2 Overall Recommendations

As a result of this demonstration, it was found that OpenFMB is not yet a standard for peer-to-peer interoperability. Gaps and options in OpenFMB's definitions, as described above, are hindrances to achieving interoperability. Further work on unambiguous definitions in the standard would aid its potential use and commercialization.

OpenFMB and its use of adapters could allow access to all devices in a unified way, protecting legacy investments and unlocking new potential in devices with limited communications capabilities, such as DER that typically use Modbus for local communication only.

OpenFMB allows peer-to-peer communication, rather than traditional hierarchical communication between devices and the utility back office found in most currently deployed distribution systems, and the autonomy of distributed intelligence unlocks the potential for new OpenFMB use cases, such as distributed Volt/VAr control.

The implementation of OpenFMB in a larger, production system will require a careful network design that takes resulting data traffic and bandwidth needs into consideration. This network design will also need to take into account application requirements to better understand each application's latency needs and capabilities.

IEC 61850 using R-GOOSE is a potentially useful alternative or addition to OpenFMB and SDG&E may wish to investigate the use of IEC 61850 using R-GOOSE further. The use of IEC 61850 with R-GOOSE could still benefit from many of the features of OpenFMB such as the use of adapters and the focus on distributed intelligence.

OpenFMB clearly shows promise as a framework for peer-to-peer communication and distributed intelligence. Further, the use of adapters in OpenFMB could help to avoid costly device replacement and extend the uses of existing devices. However, work does remain to further define and mature the OpenFMB standard as it is not yet ready for commercial adoption. It is recommended that work be continued to further define the OpenFMB standard so that it can be successfully utilized in future utility distribution system projects and deployments.

4 Technology Transfer Plan

4.1 Technology Transfer Plan

A primary benefit of the EPIC program is the technology and knowledge sharing that occurs both internally within SDG&E and across the industry. To facilitate this knowledge sharing, SDG&E will share the results of this project by announcing the availability of this report to industry stakeholders on its EPIC website, by submitting papers to technical journals and conferences, and by presentations in EPIC and other industry workshops and forums. SDG&E will also make presentations on project results to internal stakeholder groups within the company.

4.2 Adaptability to Utilities and Industry

Many aspects of OpenFMB are yet to be defined, as noted above, and the OpenFMB working group should strive to address each of these gaps to develop a truly interoperable standard. Without this further definition, there are likely to be non-interoperable implementations of OpenFMB. Further work on the OpenFMB standard is needed to provide the industry with unambiguous definitions and direction on which protocol (MQTT, DDS, AMQP) is optimal for specific circumstances or when one should be selected over another.

Currently, the OpenFMB standard is silent on payload formats and further work is needed to determine or define optimally efficient payloads. Using R-GOOSE as an additional protocol for OpenFMB is worthy of further evaluation. The industry stakeholders headed by the OpenFMB working group might consider R-GOOSE as a protocol choice, much like MQTT or DDS. In this project, proof-of-concept rules were created for orchestrating the peer-to-peer communication, which were dynamically created and deployed. Further development, including user-friendly tools, is needed to achieve production quality. A number of standards activities are evaluating dynamic rules or policies. The project recommends that the OpenFMB working group undertake this evaluation.

4.2.1 Potential OpenFMB Reference Architecture

The following section summarizes current state of the architecture to aid future OpenFMB standard development. Requirements and recommendations for this reference architecture are sourced from the NAESB RMQ.26 standard as well as potential future enhancements to the OpenFMB standard.

An OpenFMB reference architecture describes the following components:

- OpenFMB Logical Architecture
  - Operational (Data Path) Logical Architecture
  - Management Services Logical Architecture
  - Cross-Cutting Services Logical Architecture
- Node Architecture
  - Representative Hardware and Software Configurations

OpenFMB Logical Architecture

An OpenFMB operational logical architecture is related to the data path or flow of information during normal business operations. The operational logical architecture is composed of three components: application/adapter, interface, and middleware. Adapters should be developed and available for all protocols currently used by SDG&E field devices: DNP3, Modbus, IEC 61850, R-GOOSE, and ANSI C12.19. Applications and application profiles should be defined and included for all desired OpenFMB functionality (e.g., volt/var optimization, Distributed Energy Resource (DER) optimization, microgrid isolation/reconnecting).

Currently, NAESB RMQ.26 does not define specific application profiles beyond demonstration profiles or a specific canonical model. GE has developed a specific canonical model for OpenFMB that can be used to create an SDG&E canonical model and needed application profiles. In the future, this canonical model and any application profiles could be contributed back to the OpenFMB standard. In addition, as the OpenFMB standard and IEC CIM evolve, the canonical model can easily be extended or replaced due to the cleanly layered design of OpenFMB. Either a full XSD for the application profiles or only the portions relevant to the given nodes should be included for SDG&E's canonical model. Message topics should be defined and utilized for SDG&E's needs and canonical model. Based on our evaluation, one or more publish-subscribe protocols should be selected from among: MQTT, DDS, and AMQP to comprise the middleware.

Management Services Logical Architecture

An OpenFMB management services logical architecture is related to the monitoring, auditing, alerting, and updating of OpenFMB nodes. The management services layer should be flexible and allow the inclusion of additional management services plug-ins after deployment of an OpenFMB node. Updates and rollbacks of updates, as well as their timing, should be supported on all OpenFMB nodes. The updates may apply to the entire operating system or to individual components such as OpenFMB applications, adapters, and management services plug-ins.

Auditing of OpenFMB nodes should be supported. Such auditing should provide clear logging of pertinent data as well as accurate timestamps. Pertinent data should include network transfers, computing resource usage (e.g., Central Processing Unit (CPU), Random Access Memory (RAM), storage), and any installations, updates, or rollbacks. In addition to logging, data of a critical nature should be sent via an alert to an administration node.

Cross-Cutting Services Logical Architecture

An OpenFMB cross-cutting services logical architecture consists of those components which apply to both the operational logical architecture and the management services logical architecture, such as security. Security services should be based on open, standardized services appropriate for the chosen middleware (e.g., MQTT) and following the principles of defense in depth. These security services should provide mechanisms for authentication, authorization, confidentiality, non-repudiation, integrity, and auditing.

In addition, physical security, based both on the OpenFMB node hardware as well as physical placement, as well as software isolation (e.g., virtualization, containers), should be considered. Data stored (at rest) should also be held in a confidential manner (e.g., encrypted) if necessary.

Credentials should be pre-placed in OpenFMB nodes to allow for proper authentication and authorization of an administration node and any other nodes for which "out-of-the-box" communication may be necessary. The procedures for loading these credentials vary amongst deployments and may require additional action from network owners, network operators or device manufacturers. Other OpenFMB nodes may be authenticated and authorized based on policies distributed by an administration node. QoS (quality of service) should be supported on OpenFMB nodes. Further, in the presence of hardware or communications degradation, these QoS mechanisms should be used to best utilize the degraded system.

Node Architecture

Given that SDG&E already has many deployed assets that communicate using a variety of protocols, and given that dedicated OpenFMB equipment is not readily available in the market, the proposed node architecture below heavily makes use of adapters. If, in the future, native OpenFMB nodes are available, those may be more cost effective than the below approach for new assets.

For hardware, it is recommended to use a standalone device connected to each existing field asset or, should field assets be in close proximity, a standalone device may be used for multiple existing field assets. Such a device must have sufficient speed in its CPU, sufficient room in its RAM, and storage resources to implement the desired software. In our experience, we would suggest a minimum of a 1 GHz ARM processor, 512 MB of RAM, and 4 GB of storage. This device should also be capable of utilizing a variety of communications options based on previous selections by SDG&E.

For software, it is recommended to use Docker containers running atop the Linux operating system. Containerization is proving more and more popular and is more lightweight than virtual machines. Each existing device connected to the hardware would have its own container, thus isolating each OpenFMB virtual node. These containers would then have access to adapters for each legacy protocol desired (e.g., DNP3, Modbus) as well as one or more middleware protocols (e.g., DDS, MQTT, AMQP) selected based on results of our testing. The containers would also contain applications for base OpenFMB communications as well as any new applications (e.g., peer-to-peer communication). These new applications are thus easily extensible for any new OpenFMB use cases without affecting the existing devices.

This node architecture is shown in Figure 13.

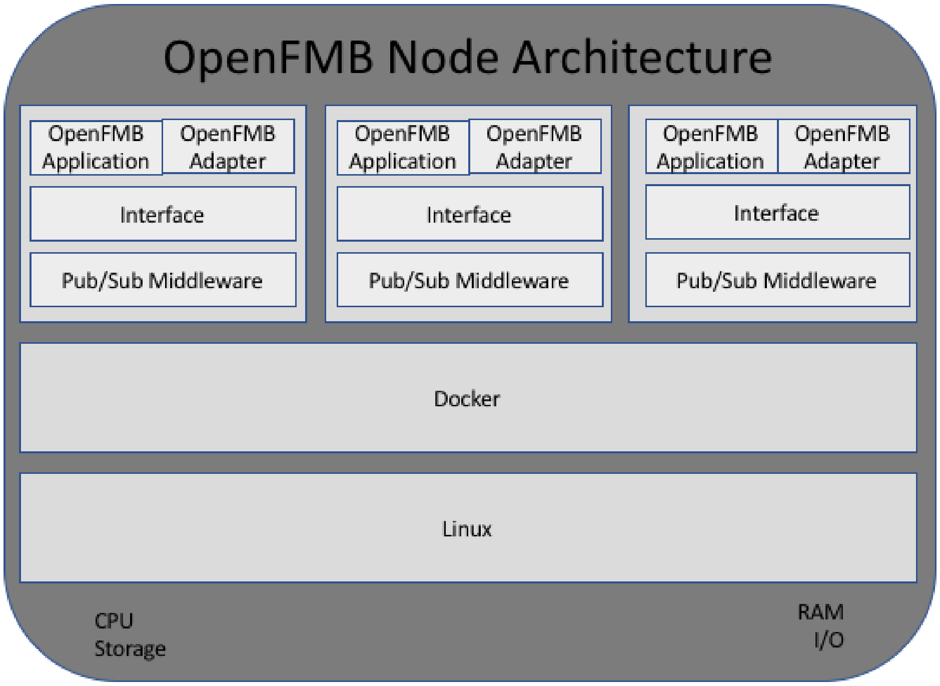


Figure 13 - OpenFMB Node Architecture

4.2.2 Dynamic Subscriptions within OpenFMB

Dynamic subscription is a finding discovered during the course of this demonstration that could be an area of future study, both for OpenFMB and for other pub/sub standards and frameworks. In pub/sub protocols, the receiver of information must subscribe to receive a published message. In the course of developing the use cases for this project, it became apparent that continuous subscription to a message is not always needed or desirable and will consume bandwidth. As such, the concept of dynamic subscription was proposed. In this scenario, a subscriber may release itself from receiving a particular message. When events on the power system dictate, the subscriber can reinitiate the subscription.

As an example, consider a device on Feeder A. In normal operating conditions, this device would likely subscribe to messages from other devices on Feeder A. However, should an event cause Feeder A to be connected electrically with Feeder B, the device may now wish to subscribe to messages from other devices on Feeder B. We have referred to this need to change subscriptions "on-the-fly" as dynamic subscription. At the application layer, the device would need to have the ability to both recognize the change in electrical network topology as well as to know which new devices and messages it would need to subscribe.

While such a capability could potentially be pre-programmed into the device or communicated from a central location, we believe further study could unlock new distributed mechanisms for these changes. It is likely a distributed mechanism would be preferable, in the event that communications to a central location is also impacted by the event as well as to avoid the latencies required to communicate to a central location during such an event. The most efficacious design of a dynamic subscription approach has yet to be explored, but could become the focus of a follow-on demonstration project.

5 Metrics and Value Proposition

5.1 Metrics

The following metrics were identified for this project and evaluated during the course of the pre-commercial demonstration. These metrics are not exhaustive given the pre-commercial demonstration approach for this project.

Identification of barriers or issues resolved that prevented widespread deployment of technology or strategy

- Develop standards for communication and interoperability of appliances and equipment connected to the electric grid, including the infrastructure serving the grid (PU Code § 8360)
  - The EPIC project demonstrated the potential value of OpenFMB in addressing interoperability issues that exist in the electric system today, with multiple vendor technologies/systems unable to interface or interact with each other in a seamless manner. OpenFMB could provide a framework that enables the coexistence of traditional IEDs or devices that operate in a centralized manner with new IEDs or devices (especially DERs) that have the capability to operate in a decentralized manner.
- Identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices, and services (PU Code § 8360)
  - This EPIC project established a potential OpenFMB framework that could be implemented in the secondary layer that sits between the enterprise layer in a utility control center, and the primary layer that sits on multiple devices or equipment in the field. Next generation of IEDs or DERs may provide the necessary communication technology and application framework that enable peer to peer communication between devices and routes the information through the OpenFMB framework to disparate systems in the backend.

Safety, Power Quality, and Reliability (Equipment, Electricity System)

The use of OpenFMB framework to deploy decentralized applications could enable interoperability and improve information sharing between field devices and backend systems. The following sub-factors could be enhanced with the use of OpenFMB:

- Reduction in outage numbers, frequency, and duration.
- Reduction in system harmonics
- Increase in the number if nodes in the power system at monitoring points
- Public safety improvement and hazard exposure reduction

5.2 Value Proposition

The purpose of EPIC funding is to support investments in R&D projects that benefit the electricity customers of SDG&E, PG&E, and SCE. The primary principles of EPIC are to invest in technologies and approaches that provide benefits to electric ratepayers by promoting greater reliability, lower costs, and increased safety. This EPIC project contributes to these primary and secondary principles in the following ways:

- Reliability – The use of OpenFMB to address interoperability challenges may provide greater reliability through potential improvements in distribution system operations through automated peer to peer volt/var control, DER management, or enhanced automatic feeder redeployment.
- Lower Costs – Utilizing OpenFMB as a framework for deploying multiple technologies has the potential to lower costs for integration of devices and applications that can help utilities operate their electric infrastructure efficiently and in a cost effective manner.

Appendix A. Use Cases

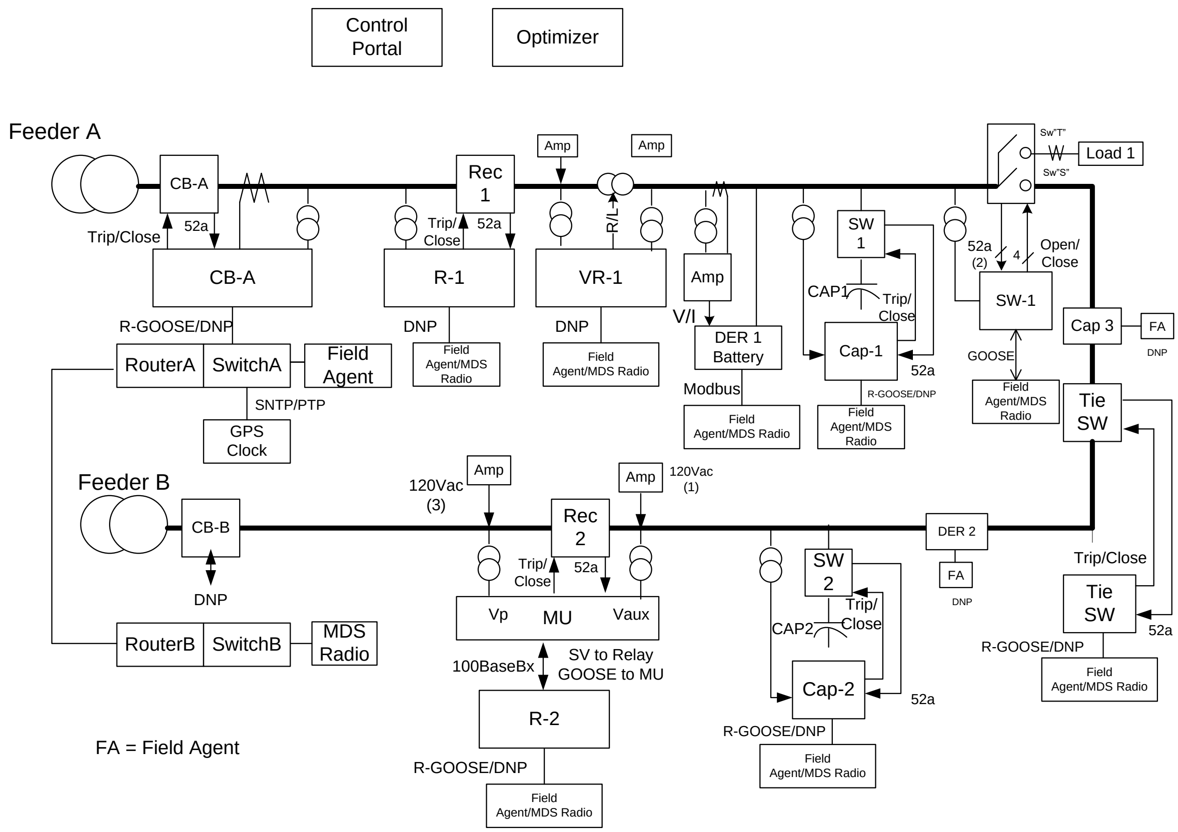
Use Case Contents

1. Introduction

The purpose of this appendix is to specify system requirements including the non-functional scenarios and user stories for the OpenFMB which focuses on the application components and the data exchange necessary to perform the analysis. The requirements are intended to specify the functional and non-functional requirements for the OpenFMB configuration and to be the pre-requisite to the Use plan documents. The Use Cases have been developed to demonstrate the use of messaging to optimize distribution system performance.

2. Reference Architecture

2.1 Reference Architecture – Figure 1



2.2 Reference Architecture – Figure 1 Device Names

Note: Device Names and abbreviations

Device Description	***Device Abb.***
Vendor A - Circuit Breaker A	CB-A
Vendor A - Capacitor 1	Cap 1
Vendor A - Capacitor 2	Cap 2
Vendor A - Tie Switch	Tie SW
Vendor A - Recloser 2	R-2
Vendor A - Virtual Capacitor 3	Cap 3
Vendor A - Virtual DER	Der 2
Vendor B Recloser 1	R-1
Vendor B Voltage Regulator	VR-1
Vendor B Load Switch	SW-1
Vendor C DER	DER 1
Vendor B Circuit Breaker B	CB-B

3. Actors

3.1 Use Case Actors

Actor Name *see Actor List*	*Actor Type* *see Actor List*	*Actor Description* *see Actor List*	*Further info*
OpenFMB	System, application	System framework and reference architecture for distributed intelligent nodes interacting with each other through loosely coupled, peer -to-peer messaging for field devices and systems along the electric value chain.	Real
Control Portal	System, application	Application that provides a User Interface to visualize the circuit network, display measurement values and provide limited control capability for network devices.	Real
Network Diagram	System, application, data	Network Diagrams SDG&E provided circuits C411 and C387. The Circuits will be displayed on the Control Portal.	Real
Optimizer	System, application	Application which optimizes the resources included in the Vol/Var Use Cases. Optimization is done using based on defined business rules.	Simulated
Field Agent	device	Field agent SW & HW device that will communicate with the "edge", field devices. The Field Agents includes Radio, Communication, FA nodes are connected to each Field Device and connected to the OpenFMB.	Real
Operator	person	Operator of the Use Case scripts. This actor is required for Use Case operations as the Use system is not fully autonomous.	Real
Breaker Relay	device	The Breaker Relay feeder protection system provides feeder protection, control, monitoring and metering in an integrated package.	Real

Actor Name *see Actor List*	*Actor Type* *see Actor List*	*Actor Description* *see Actor List*	*Further info*
Capacitor Relay	device	The Capacitor Relay provides protection functions designed specifically to protect shunt capacitor banks.	Real
Tie Switch Relay	device	The controller system is a device designed to act as Tie Switch to demonstrate Use Cases.	Real
Recloser Relay	device	The Advanced Recloser Control offers protection and communications capabilities for Automatic Network Reconfiguration in the event of a fault.	Real
Voltage Regulator Relay	device	The Voltage Regulator Controller to optimize System Voltage and control system voltage.	Real
Load Relay	device	The load simulation relay provides three-phase restraint current inputs.	Real
PMU	device	Highly accurate measuring device for System electrical measure, time tags, and frequency synchronization.	Real
Battery Inverter	device	Inverter that connects battery to the VVC System. Assumed to be capable of operation as a rectifier. Controllable up in range zero to current maximum capability of solar panel.	Real
Flexible Load	device	Controllable load to simulate Critical customer loads; both load shed and non-load shed components.	Simulated
Communication	device	Interconnection of devices and systems using 900mhz and WIFI.	Real
RTDS	System, application	Power system simulation software	Simulator

4. General Triggering Events, Preconditions, Assumptions

4.1 Use Case Triggering Event, Preconditions, Assumptions

Actor/System/Information/Contract	***Triggering Event***	***Pre-conditions***	***Assumption***
Operator	Optional human operator. May observe operations of Use Case demonstrations and provide Operator inputs as required	Operator trained in use of the system	
Optimizer	There is a control simulator for managing control commands to the distribution grid. The controls are based on Use Case Using steps.	Distribution Network (2 Circuits) are imported into the Control Portal	Interaction with the Control Portal and Optimizer during Using of OpenFMB
Control Portal	Control Portal provides the visualization, monitoring and display. Measurement and Control values trigger changes the display	Control Portal is preconfigured and the distribution network circuits have been imported into the application.	
Devices (Relays)	Relay events are defined in the Use Cases. Defined events sends and receives messages via GOOSE, R-GOOSE or OpenFMB messages.	Relays are preconfigured and are connected to the distribution and communication network	Device Relays are pre-wired and connected to the networks.
Distribution Network	Distribution Network with 2 circuits connected with a tie switch have been preconfigured along with all network devices	Distribution Network (2 Circuits) have full connectivity from Circuit Breaker to network devices defined in the Use Case	Network model is provided in CIM/RFD
Messaging Protocols	MQTT, DDS, GOOSE, R-GOOSE messaging protocols.	Machine to Machine preconfigured with MQTT, DDS, GOOSE, R-GOOSE	
Communication	Communication network along with Field Agents	Communication Network is preconfigured with 2	Radio equipment and communication network

Network	have been configured. Send & receive messages can be triggered from the relays, Control Portal or Optimizer.	separate networks. Each circuit preconfigure with a separate communication network.	is preconfigured and has the ability to ping all devices on the network

5. Use Case 1a - OpenFMB Connection to Relays & Virtual DER / Cap Bank

5.1 Use Case Description - UC 1a OpenFMB Connection to Relays & Virtual DER / Cap Bank

UC 1a: OpenFMB Connection to Relays and Virtual DER / Cap Bank

Objective:

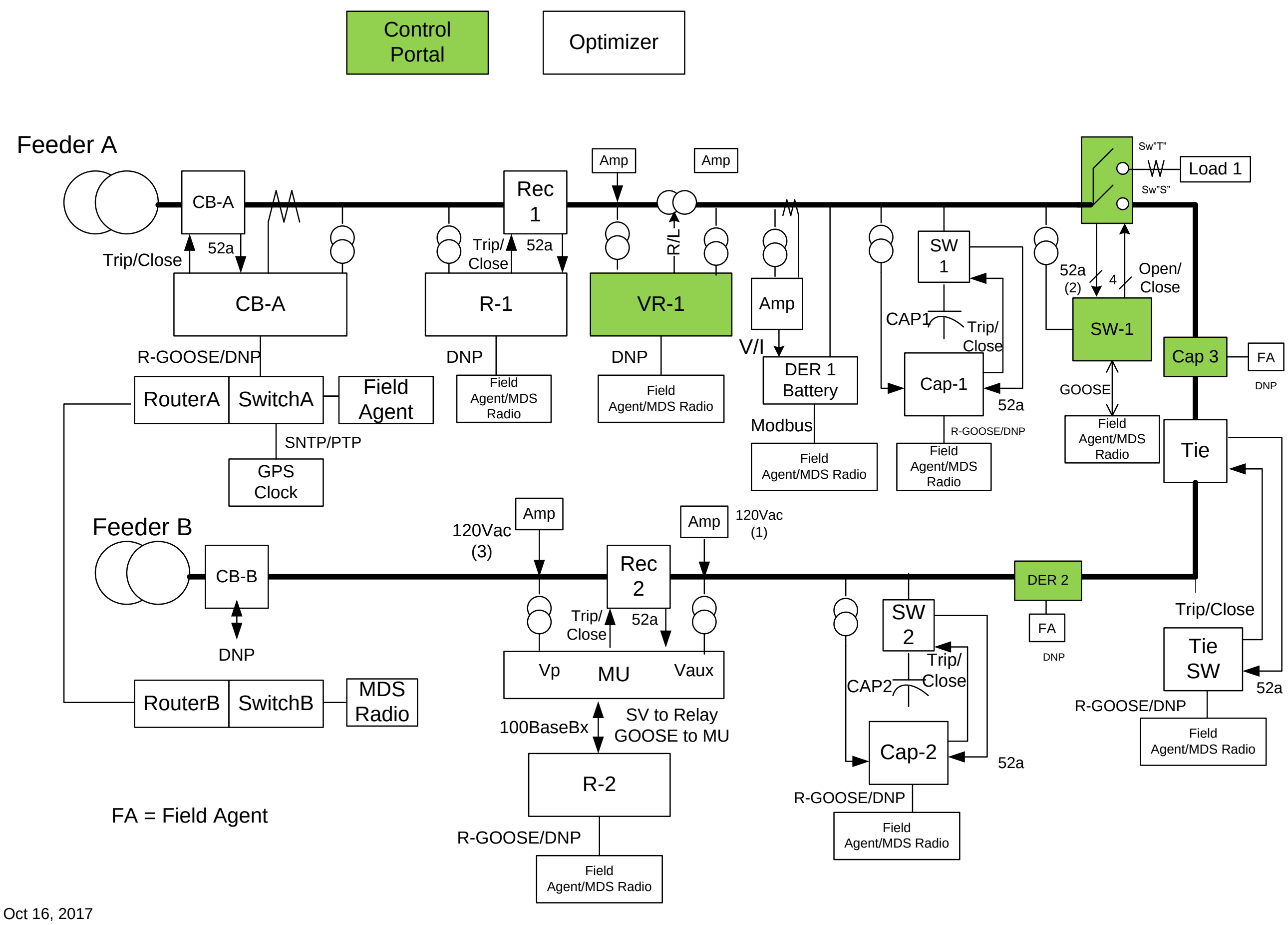
- Demonstrate the use of OpenFMB to communicate from a Control Portal to a field device showing:
  - Status – measurement values
  - Control – change status

Description:

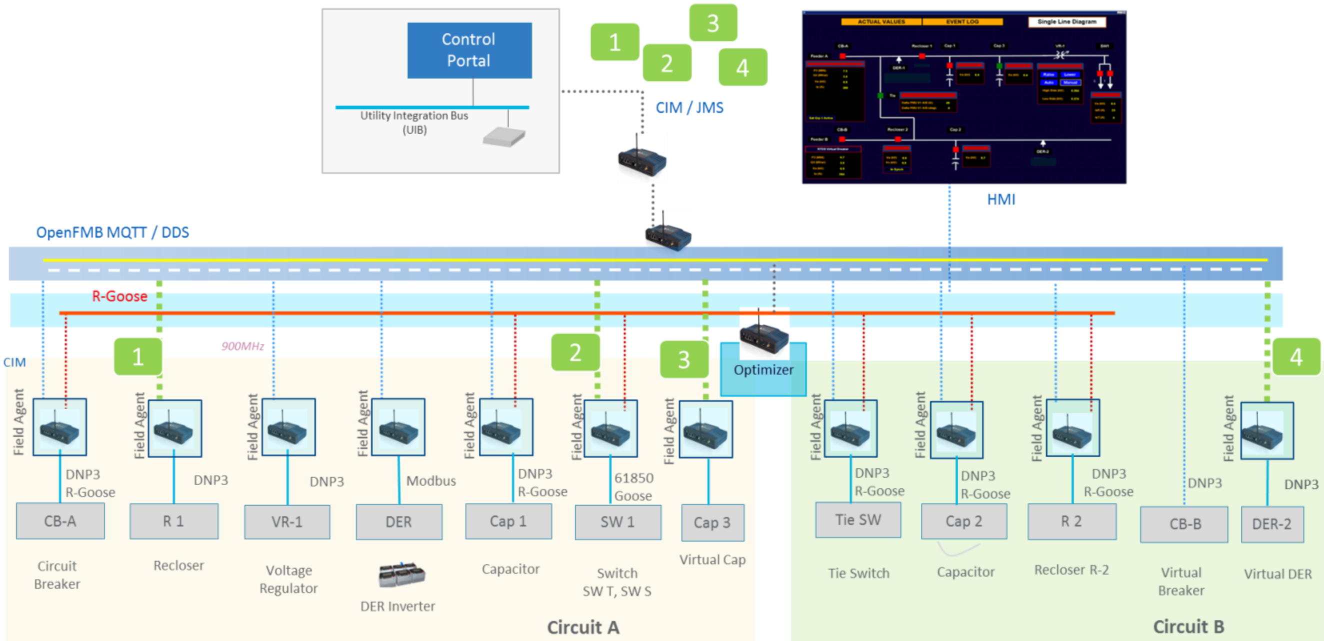
- Operation of Recloser 1 (R-1) (Open/Close) and Voltage measurements are to be made through OpenFMB messaging to the Recloser 1 (R-1) relay.
- Control and status of Switch 1 SW-1 are to be demonstrated from the Control Portal through OpenFMB to the Switch (SW-1).
- Control and Status of the Virtual DER (DER 2)
- Control and Status of the Virtual Cap Bank (Cap 3)

5.2 Use Case Diagram - UC 1a OpenFMB Connection to Relays & Virtual DER / Cap Bank

Logical and IO Diagram



5.3 Use Case Diagram - UC 1a OpenFMB Connection to Relays & Virtual DER / Cap Bank



Data Flow	***Data Flow Summary***	***Protocol***
1.	Control Portal (CP) → Field Agent → RECLOSER 1 (R-1)	CP →OpenFMB(MQTT) → DNP → RECLOSER 1 (R-1)
2.	Control Portal (CP) → Field Agent → Switch (SW-1)	CP →OpenFMB(MQTT) → DNP → Switch (SW-1)
3.	Control Portal (CP) → Field Agent → Virtual DER (DER 2)	CP →OpenFMB(MQTT) → DNP → Virtual DER (DER 2)
4.	Control Portal (CP) → Field Agent → Virtual Cap Bank (Cap 3)	CP →OpenFMB(MQTT) → DNP → Virtual Cap Bank (Cap 3)

5.4 Pre-Conditions - UC 1a OpenFMB Connection to Relays & Virtual DER / Cap Bank

Pre-Conditions	*Description*
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	OpenFMB pre-configured
3.	Multiple field agents connected and communicating via OpenFMB
4.	Optimizer Pre-configured
5.	Control Portal Pre-configured
6.	RTDS is Active
7.	Network Model with Switchable Devices (2 Circuits)
8.	Tie Switch is Open
9.	Cap 1 is Open
10.	Cap 2 is Open
11.	R-1 is Closed
12.	VR-1 is Auto Mode
13.	SW-1 is Closed (2 positions)
14.	CB-A is Closed
15.	CB-B is Closed
16.	On Power-up of the Virtual DER and Field Agent, the following registers shall be WRITTEN as part of initialization OR via the Control Portal: 40007 – 2 – RESET 40008 – 2 – Set Voltage Source Inverter – PQ Mode 40101 – 256 – Set for Voltage / Watt mode of operation 40009 – 100 – Initial Real Power Set Point 40010 – 50 – Initial Reactive Power Set Point

6. Use Case 2a - Var Control

6.1 Use Case Description – UC 2a Var Control

UC 2a: Var Control

Objective:

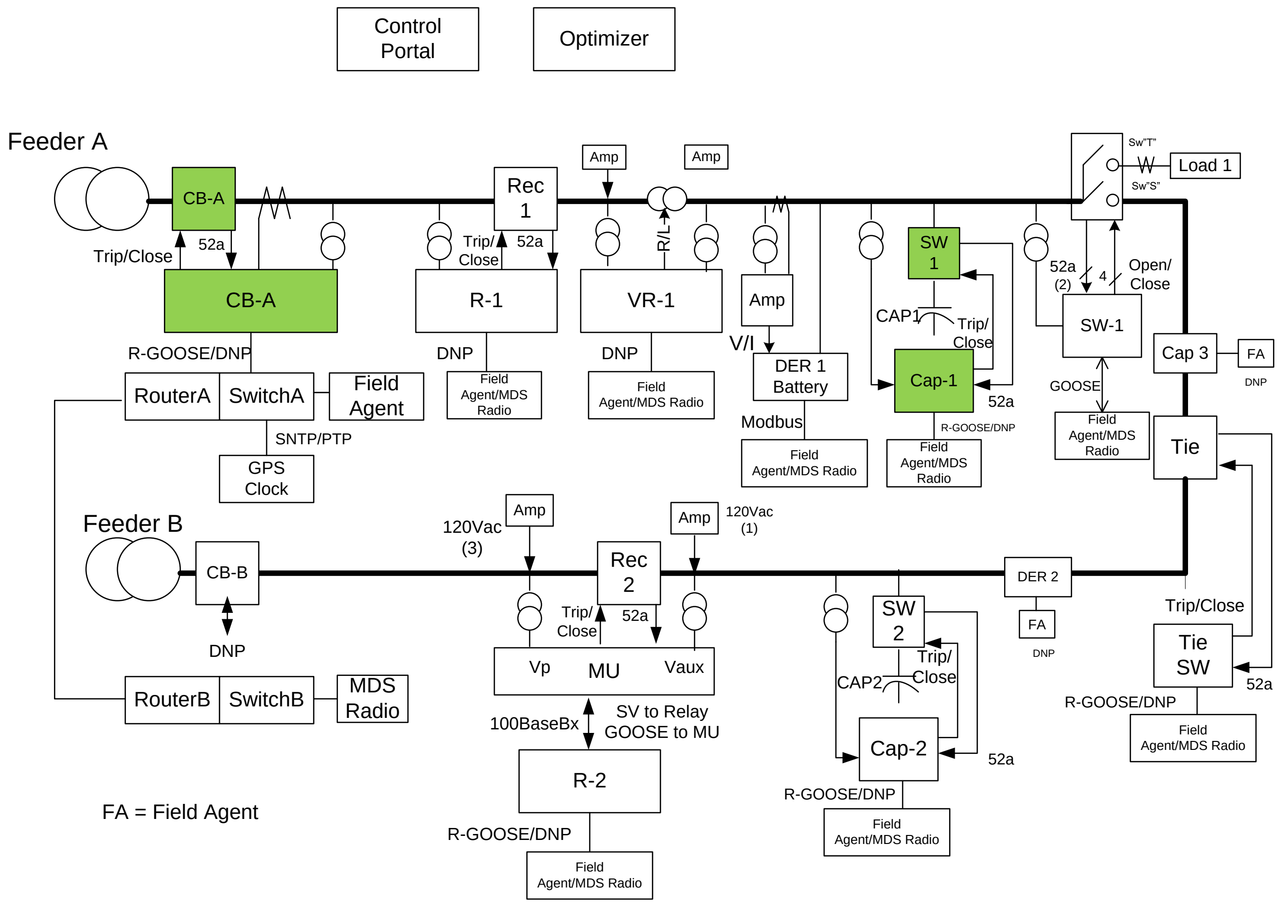
- Evaluate R-GOOSE as an alternative Pub-Sub protocol under the OpenFMB standard / framework.

Description:

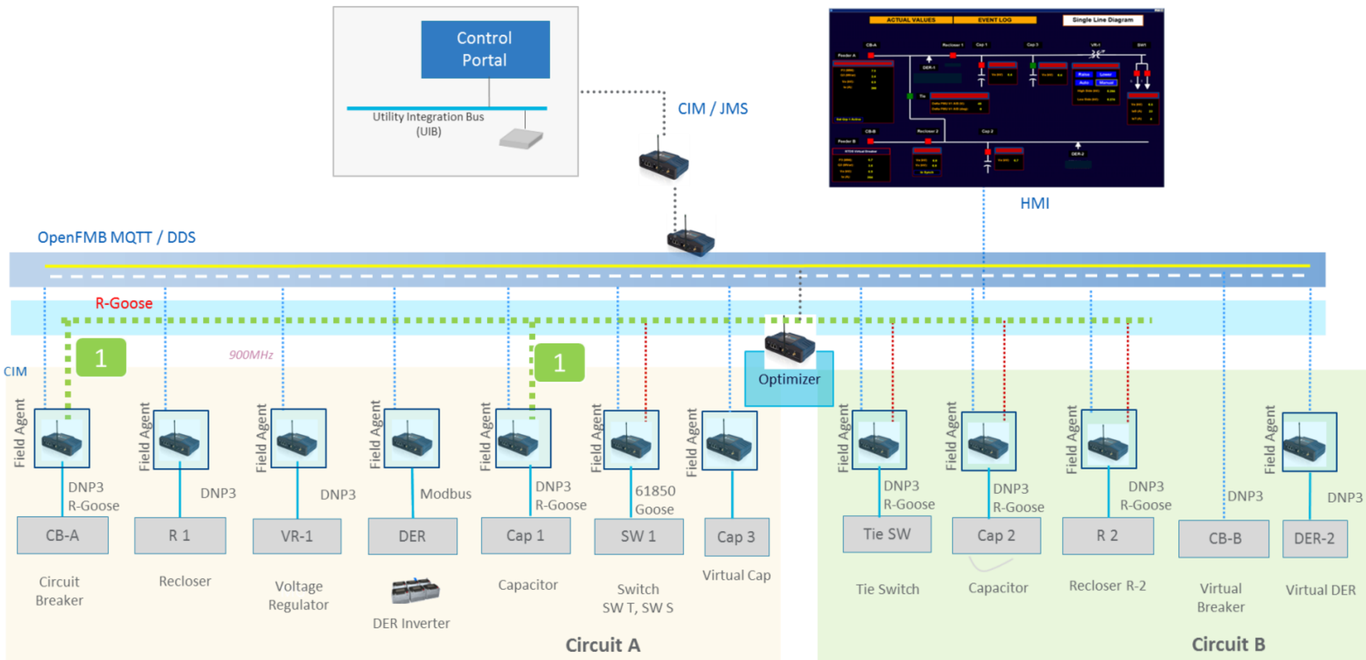
- Create a 2-line power system (Line A and Line B) with communicable devices on different networks on each line. Measure the Vars at the breaker end of Feeder A (CB-A).
- When the Vars exceed a set-point, send a R-GOOSE message from CB-A to Cap 1 to cut-in the capacitor at that location.
- Close Capacitor Cap 1

6.2 Use Case Diagram - UC 2a Var Control

Logical and IO Diagram



6.3 Use Case Diagram - UC 2a Var Control



Data Flow	*Data Flow Summary*	*Protocol*
1.	CB-A → CAP 1	CB-A → R-GOOSE → CAP 1

6.4 Use Case Pre-Conditions – UC 2a Var Control

Pre-Conditions	***Description***
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	OpenFMB pre-configured
3.	Multiple field agents connected and communicating via OpenFMB
4.	Optimizer Pre-configured
5.	Control Portal Pre-configured
6.	RTDS is Active
7.	Network Model with Switchable Devices (2 Circuits)
8.	Tie Switch is Open
9.	Cap 1 is Open
10.	Cap 2 is Open
11.	R-1 is Closed
12.	VR-1 is Auto Mode
13.	SW-1 is Closed (2 positions)
14.	CB-A is Closed
15.	CB-B is Closed

7. Use Case 2b Man-in-the-Middle Augmented Voltage/Var Control

7.1 Use Case Description – UC 2b Man-in-the-Middle Augmented Voltage/Var Control

UC 2b Man-in-the-Middle Augmented Voltage/Var Control

Objective:

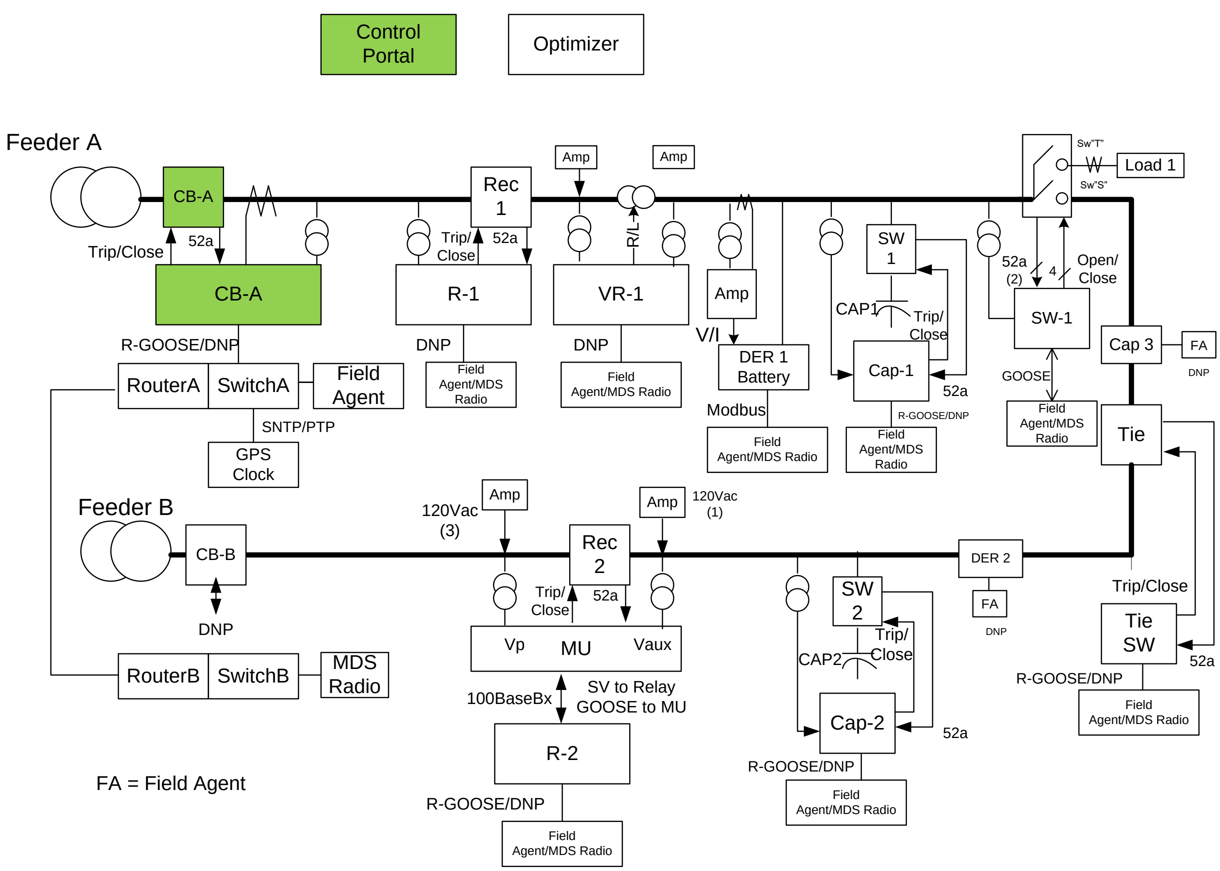
- Demonstrate manual control and operation using OpenFMB

Description:

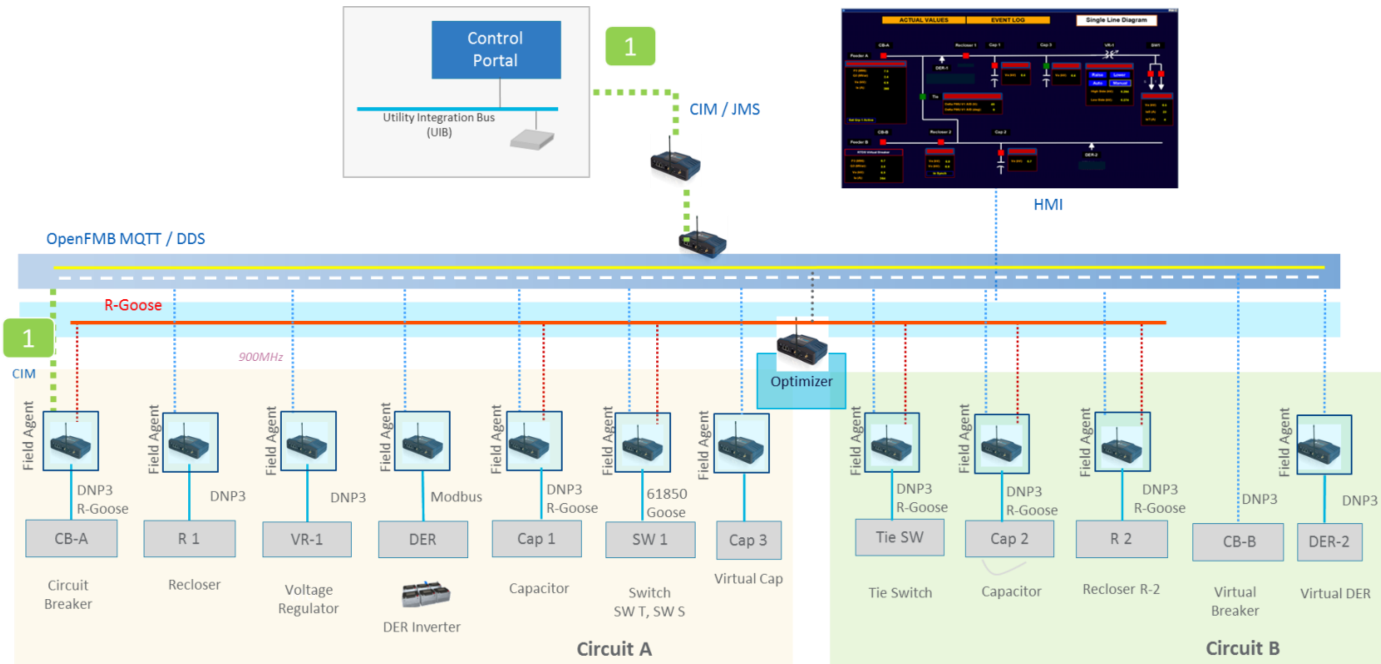
- If, after closing Capacitor 1, the var level is still above the setting threshold in the CB-A, a OpenFMB alarm of "over VAR" will be issued by the CB-A relay.
- This alarm is to be received by the Control Portal and indicated.
- Pre-condition VR-1 is in manual mode.

7.2 Use Case Diagram – UC 2b Man-in-the-Middle Augmented Voltage/Var Control

Logical and IO Diagram



7.3 Use Case Diagram – UC 2b Man-in-the-Middle Augmented Voltage/Var Control



Data Flow	***Data Flow Summary***	***Protocol***
1.	CB-A → Field Agent →Control Portal (CP)	CB-A → DNP → OpenFMB(MQTT) → CP

7.4 Use Case Pre-Conditions – UC 2b Man-in-the-Middle Augmented Voltage/Var Control

Pre-Conditions	***Description***
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	OpenFMB pre-configured
3.	Multiple field agents connected and communicating via OpenFMB
4.	Optimizer Pre-configured
5.	Control Portal Pre-configured
6.	RTDS is Active
7.	Network Model with Switchable Devices (2 Circuits)
8.	Tie Switch is Open
9.	Cap 1 is Closed
10.	Cap 2 is Open
11.	R-1 is Closed
12.	VR-1 is Manual Mode (not a normal operating state)
13.	SW-1 is Closed (2 positions)
14.	CB-A is Closed
15.	CB-B is Closed

8. Use Case 2c – Peer-to-Peer Voltage/Var Control

8.1 Use Case Description – UC 2c Peer-to-Peer Voltage/Var Control

UC 2c Peer-to-Peer Voltage/Var Control

Objective:

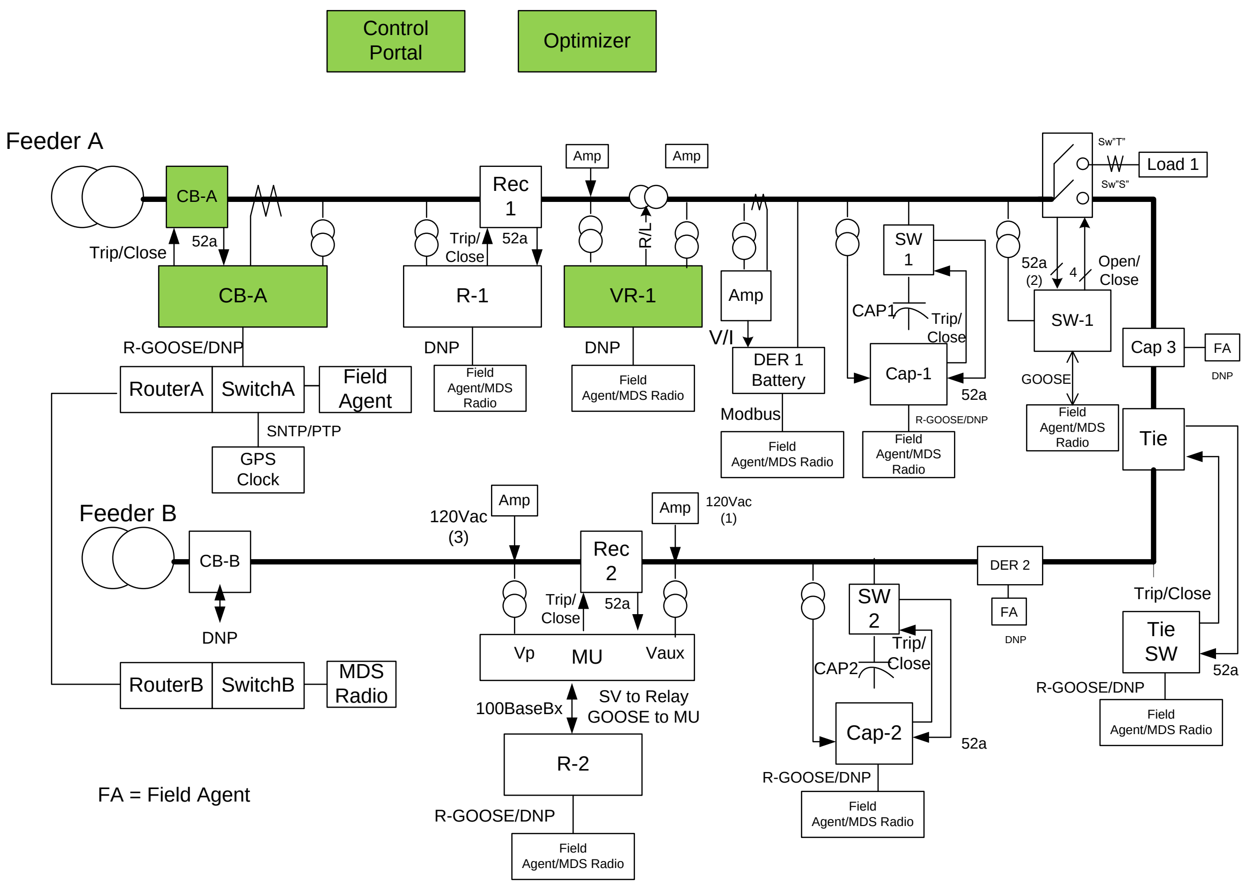
- Demonstrate automated control or operation using OpenFMB

Description:

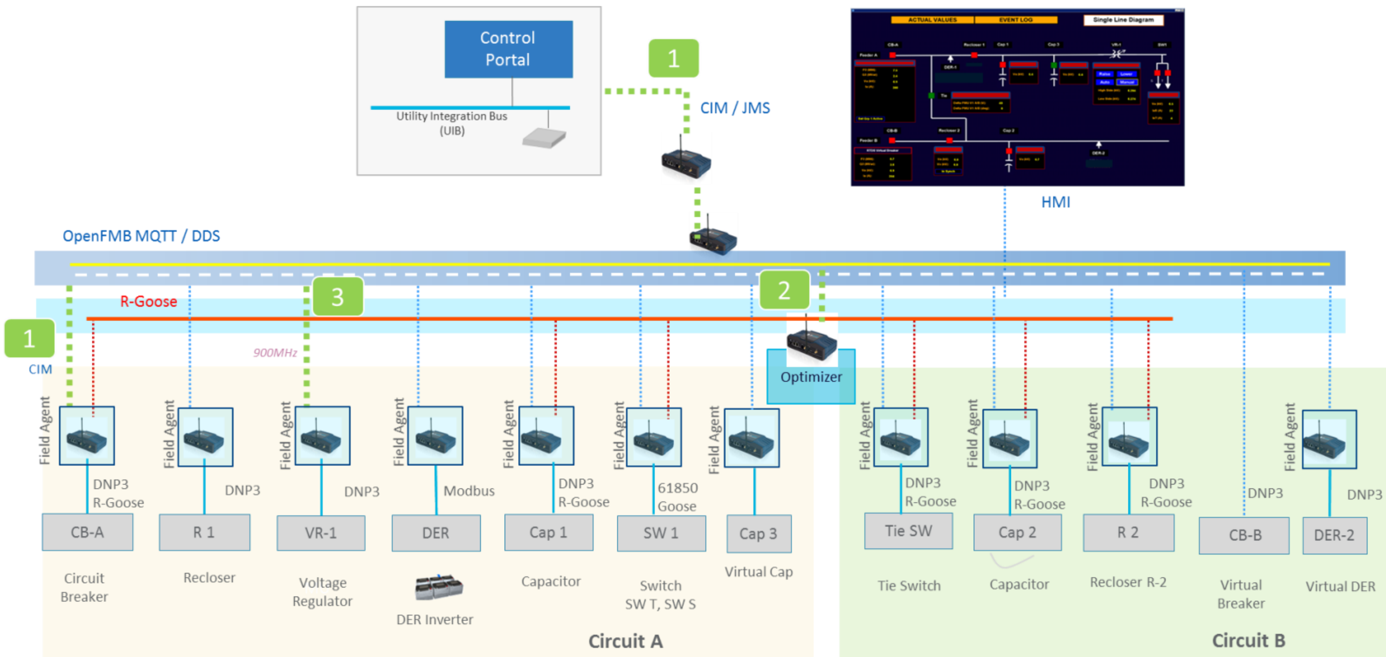
- If, after closing Capacitor 1, the var level is still above the setting threshold in the CB-A, an alarm of "over VAR" will be issued by the CB-A.
- This alarm is to be received by the Optimizer and the Optimizer then places VR-1 Voltage Regulator in auto mode via an OpenFMB command.
- Pre-Condition VR-1 manual mode
- Pre-Condition Cap 1 is closed
- RTDS raises VAR loading prior to start of test

8.2 Use Case Diagram – UC 2c Peer-to-Peer Voltage/Var Control

Logical and IO Diagram



8.3 Use Case Diagram – UC 2c Peer-to-Peer Voltage/Var Control



Data Flow	*Data Flow Summary*	*Protocol*
1.	CB-A → Field Agent →Control Portal (CP)	CB-A → DNP → OpenFMB(MQTT) → CP
2.	CB-A → Field Agent →Optimizer	CB-A → DNP "over VAR "→ Field Agent (CIM) → OpenFMB(MQTT) → "over VAR" alarm Optimizer
3.	Optimizer → CIM → OpenFMB(MQTT) → VR-1	Optimizer → CIM → OpenFMB(MQTT) → Field Agent (CIM) → DNP → VR-1 (Auto Mode)

8.4 Use Case Pre-Conditions – UC 2c Peer-to-Peer Voltage/Var Control

Pre-Conditions	***Description***
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	OpenFMB pre-configured
3.	Multiple field agents connected and communicating via OpenFMB
4.	Optimizer Pre-configured
5.	Control Portal Pre-configured
6.	RTDS is Active
7.	Network Model with Switchable Devices (2 Circuits)
8.	Tie Switch is Open
9.	Cap 1 is Closed
10.	Cap 2 is Open
11.	R-1 is Closed
12.	VR-1 is manual Mode
13.	SW-1 is Closed (2 positions)
14.	Control Portal displays measurement values
15.	CB-A is Closed
16.	CB-B is Closed
17.	RTDS lowers the VAR loading below threshold

9. Use Case 2d – Voltage Override

9.1 Use Case Description – UC 2d Voltage Override

UC 2d Voltage Override

Objective:

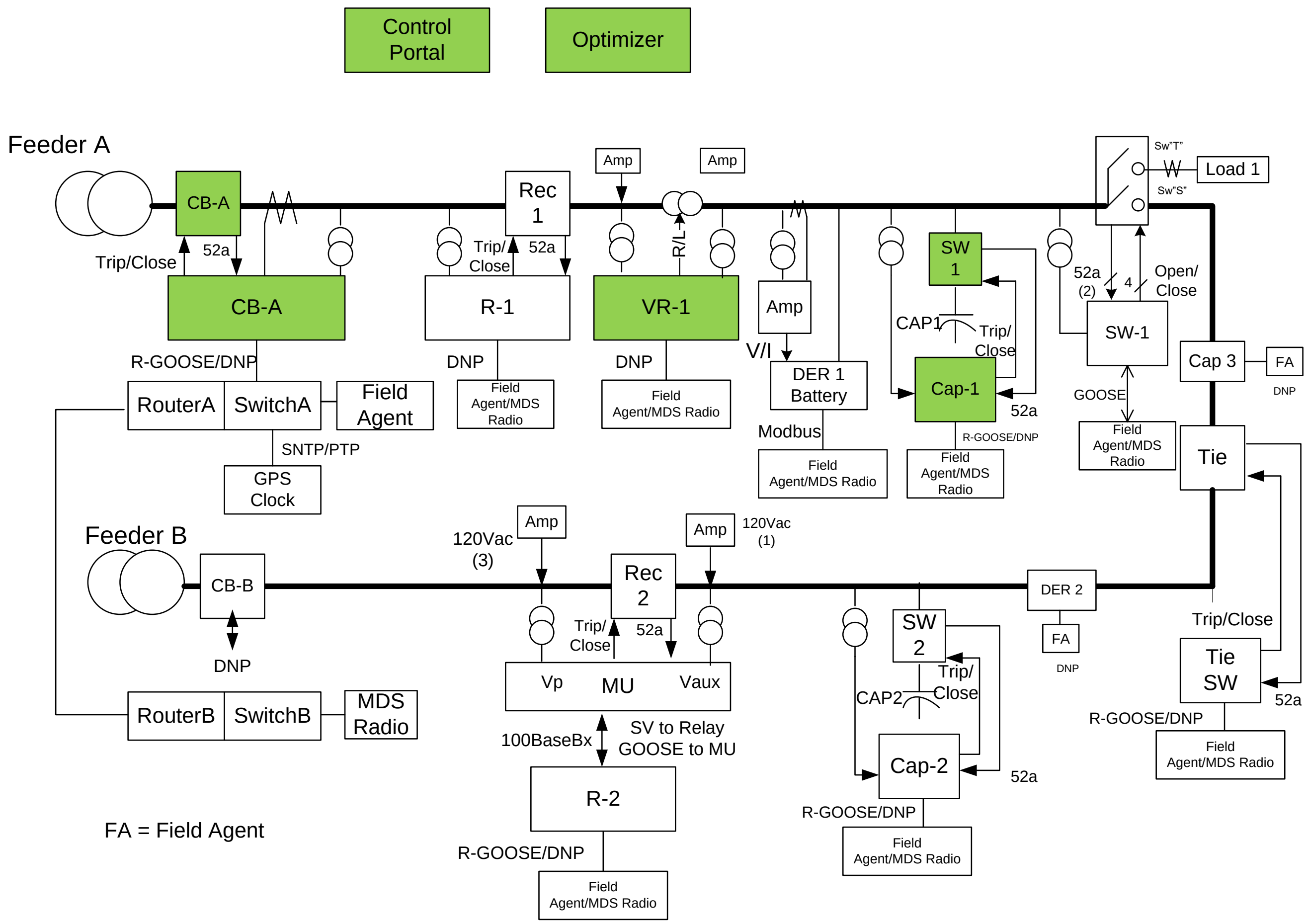
- Demonstrate the communication of the rejection of manual control and subsequent automatic response based on prevailing local condition using OpenFMB.

Description:

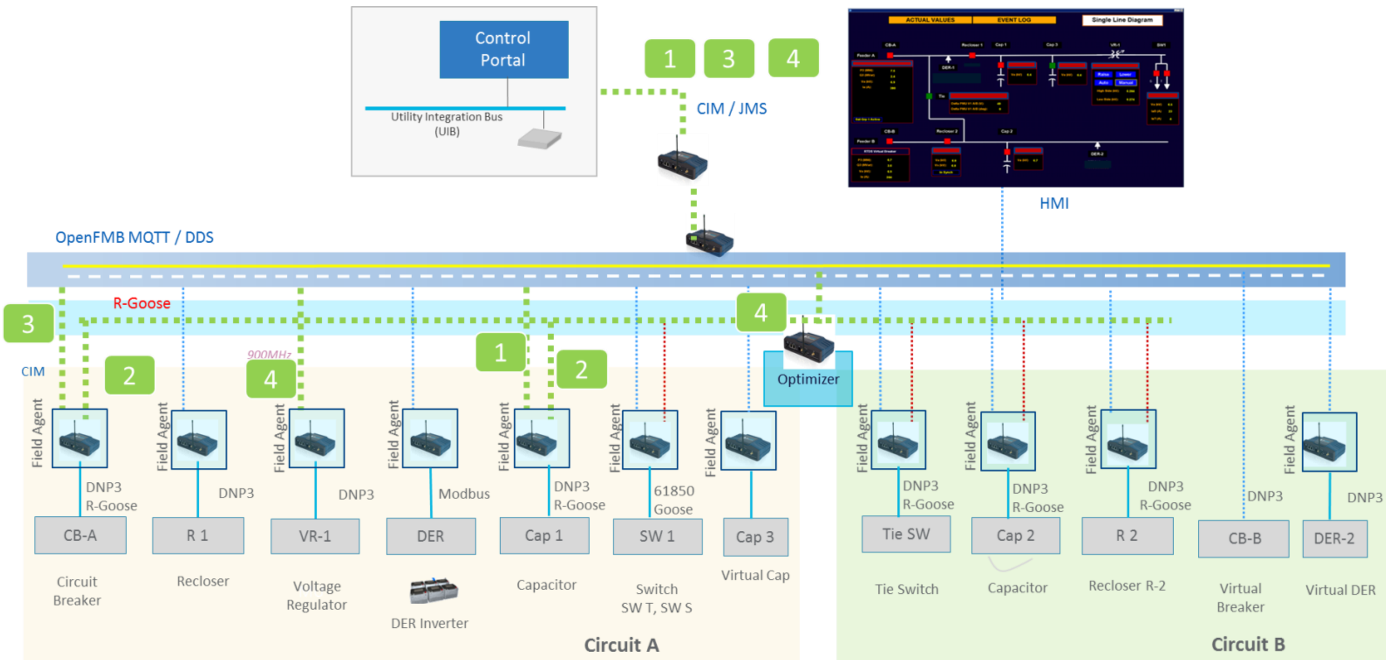
- Control Portal sends a close command to CAP 1
- If the voltage on CAP 1 is too high, CAP 1 refuse the CLOSE control and send a message to the CB-A indicating refusal of the Cap 1 devices to execute the requested close action.
- An OpenFMB message is issued indicating such from CB-A and is to be displayed on the Control Portal.
- Detection of Over-Voltage shall be transmitted to the Optimizer which will then enable the Voltage Regulator.
- Pre-condition: Voltage Regulator (VR-1) Manual Mode & high voltage (circuit A) through RTDS
- Post-condition: Voltage Regulator (VR-1) turned to Automatic Mode

9.2 Use Case Diagram – UC 2d Voltage Override

Logical and IO Diagram



9.3 Use Case Diagram – UC 2d Voltage Override



Data Flow	*Data Flow Summary*	*Protocol*
1.	Control Portal (CP) → OpenFMB(MQTT) → Field Agent → CAP 1	CP → CIM/JMS → OpenFMB(MQTT) → Field Agent (CIM) → DNP → CAP 1 (Close)
2.	CAP 1 → CB-A	CAP 1 → R-GOOSE → CB-A
3.	CB-A → Refuse Close → Control Portal (CP)	CB-A → DNP → Field Agent (CIM) → OpenFMB(MQTT) → CIM/JMS → CP
4.	Control Portal (CP) → Optimizer → VR-1	CP → CIM/JMS → OpenFMB(MQTT) → Optimizer → OpenFMB(MQTT) → Field Agent (CIM) → DNP → VR-1 (Auto Mode)

9.4 Use Case Pre-Conditions – UC 2d Voltage Override

Pre-Conditions	***Description***
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	OpenFMB pre-configured
3.	Multiple field agents connected and communicating via OpenFMB
4.	Optimizer Pre-configured
5.	Control Portal Pre-configured
6.	RTDS is Active
7.	Network Model with Switchable Devices (2 Circuits)
8.	Tie Switch is Open
9.	Cap 1 is Open
10.	Cap 2 is Open
11.	R-1 is Closed
12.	VR-1 is Manual Mode
13.	SW-1 is Closed (2 positions)
14.	Control Portal displays measurement values
15.	CB-A is Closed
16.	CB-B is Closed
17.	RTDS voltage needs to raise to 1.6 PU

10. Use Case 3a – Inter-network Var Control

10.1 Use Case Description – UC 3a Inter-network Var Control

UC 3a Inter-network Var Control

Objective:

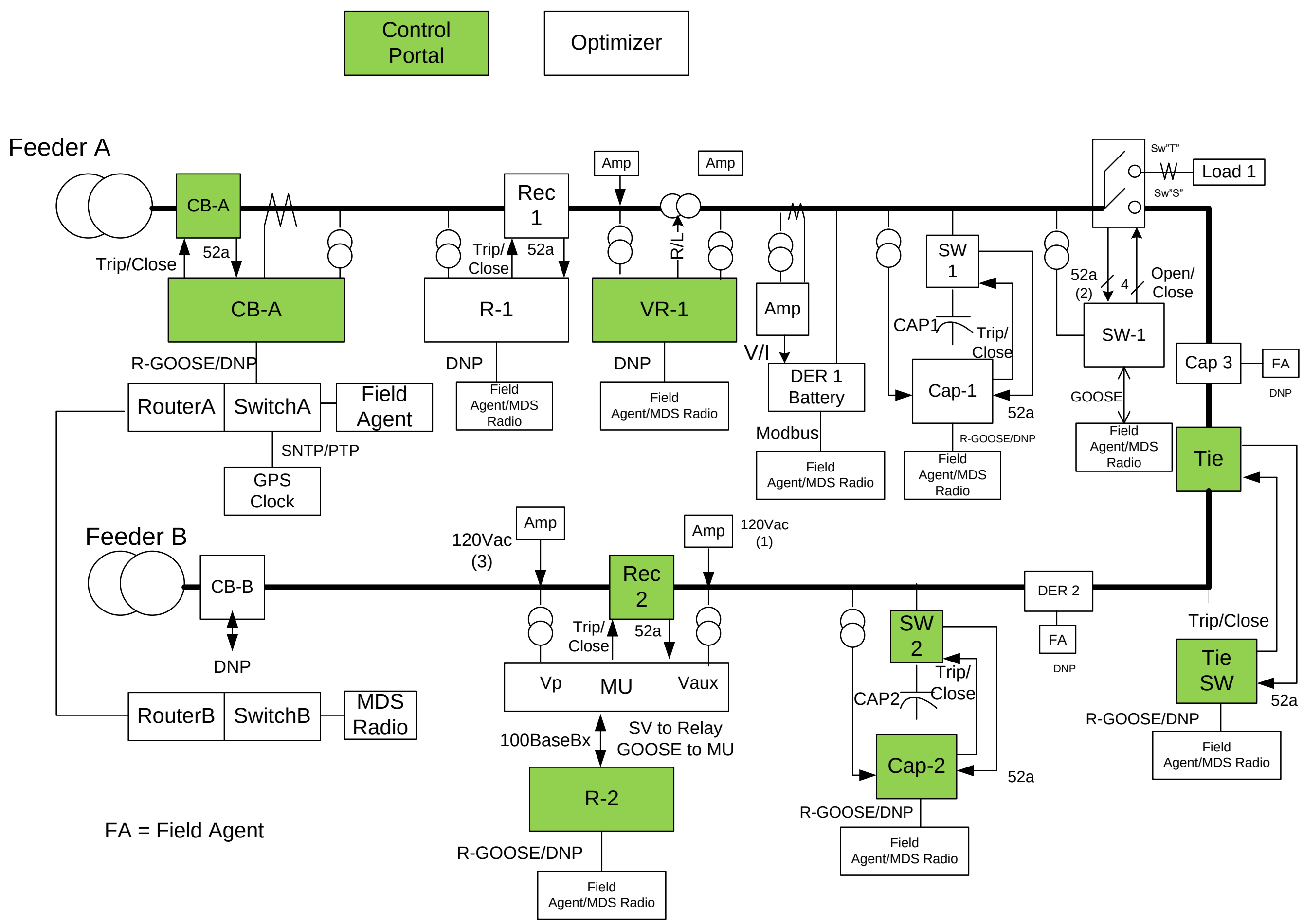
- Demonstrate Inter-network communication capability of OpenFMB

Description:

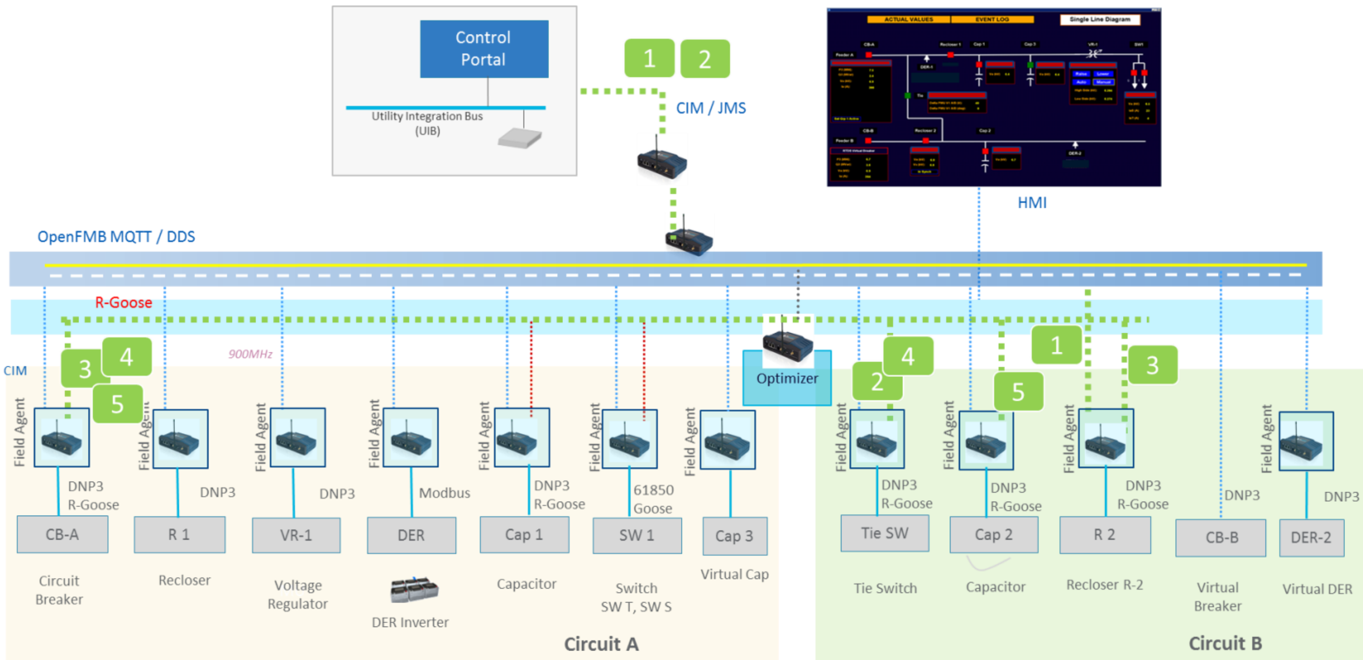
- Building on Test Case 2a, b, c, d.
- Using OpenFMB issues command from the Control Portal to open Recloser 2 R-2 and then close the TIE switch (Tie SW).
- The status of Recloser 2 and Tie Breaker are monitored by the R-2 and Tie SW relays respectively.
- This information is then sent – internetwork via R-GOOSE to CB-A.
- Var load on the feeder is then increased above the setting threshold.
- The CB-A then makes a determination to close Capacitor 2 for additional var support.
- Pre-condition: Capacitor Bank 1 is CLOSED and the Voltage Regulator (VR-1) is manual mode.
- Pre-condition: CB-B is open

10.2 Use Case Diagram – UC 3a Inter-network Var Control

Logical and IO Diagram



10.3 Use Case Diagram – UC 3a Inter-network Var Control



Data Flow	*Data Flow Summary*	*Protocol*
1.	Control Portal (CP) → OpenFMB(MQTT) → Field Agent → R-2	CP → CIM/JMS → OpenFMB(MQTT) → Field Agent (CIM) → DNP → R-2 (Open)
2.	Control Portal (CP) → OpenFMB(MQTT) → Field Agent → c	CP → CIM/JMS → OpenFMB(MQTT) → Field Agent (CIM) → DNP → Tie SW (Close)
3.	R-2 → CB-A	R-2 → R-GOOSE → CB-A (Status Change)
4.	Tie SW → CB-A	Tie SW → R-GOOSE → CB-A (Status Change)
5.	CB-A → CAP 2	CB-A → R-GOOSE → CAP 2 (Close)

10.4 Use Case Pre-Conditions – UC 3a Inter-network Var Control

Pre-Conditions	***Description***
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	OpenFMB pre-configured
3.	Multiple field agents connected and communicating via OpenFMB
4.	Optimizer Pre-configured
5.	Control Portal Pre-configured
6.	Network Model with Switchable Devices (2 Circuits)
7.	Tie Switch is Open
8.	Cap 1 is Close
9.	Cap 2 is Open
10.	R-1 is Closed
11.	VR-1 is manual
12.	SW-1 is Closed (all 2 positions)
13.	Control Portal displays measurement values
14.	R-2 is Closed
15.	CB-B is Open

11. Use Case 3b – Peer-to-Peer Volt/Var Control

11.1 Use Case Description – UC 3b Peer-to-Peer Volt/Var Control

UC 3b Peer-to-Peer Volt/Var Control

Objective:

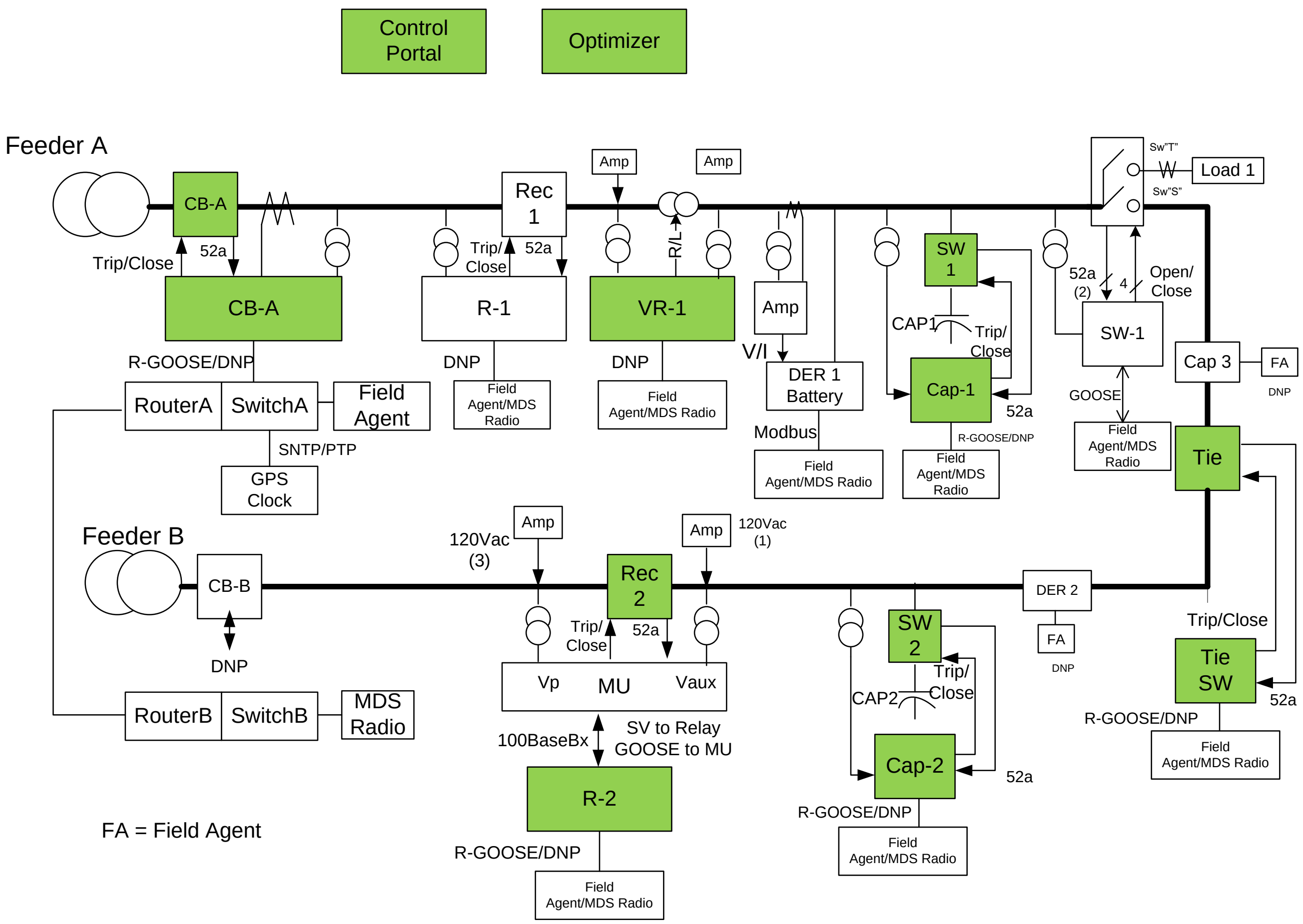
- Demonstrate Peer-to-Peer communication capability of OpenFMB to achieve progressive Var support.

Description:

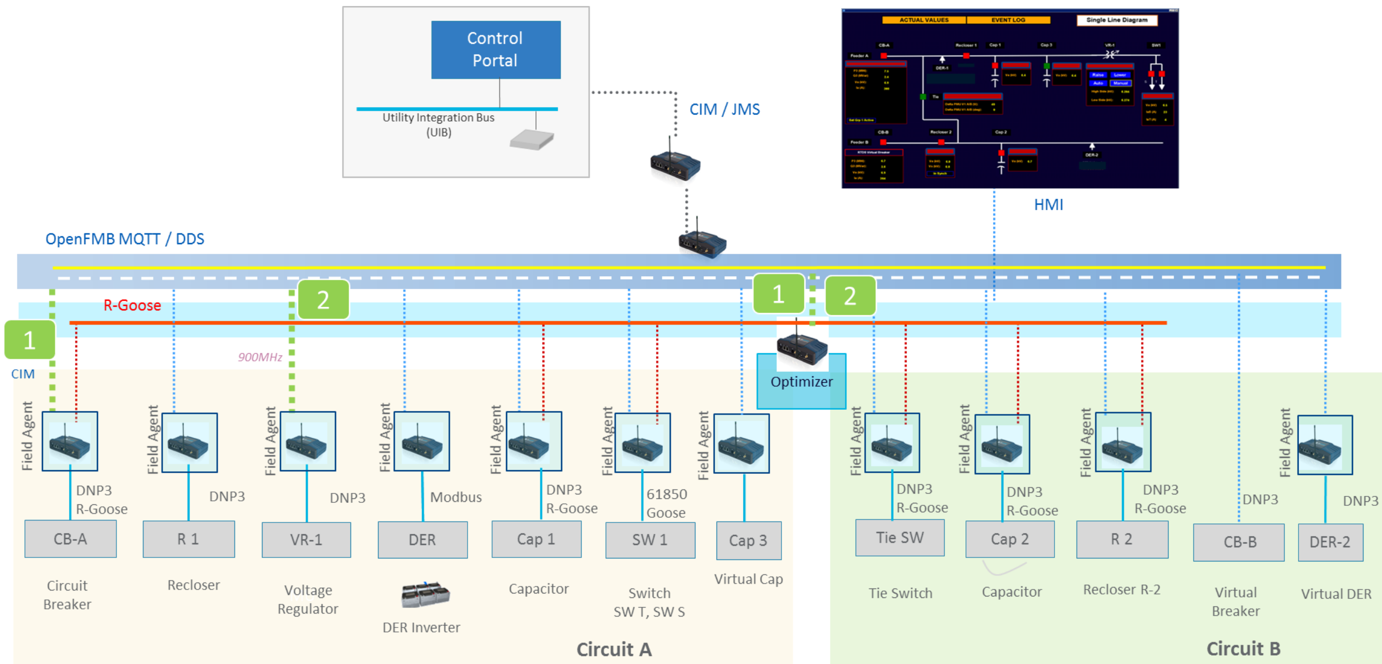
- Given that Capacitor 1 is closed AND the Tie SW is closed AND Capacitor Bank 2 is closed.
- The var load on the line is then further increased above the setting threshold.
- The CB-A then issues a signal (High Var) to the Optimizer that additional var support is needed.
- Upon receipt of a High Var message, the Optimizer will then switch the Voltage Regulator (VR-1) to manual mode.
- Pre-Condition: Voltage Regulator (VR-1) is in Auto mode

11.2 Use Case Diagram – UC 3b Peer-to-Peer Volt/Var Control

Logical and IO Diagram



11.3 Use Case Diagram – UC 3b Peer-to-Peer Volt/Var Control



Data Flow	***Data Flow Summary***	***Protocol***
1.	CB-A → Optimizer	CB-A → DNP → Field Agent (CIM) → OpenFMB(MQTT) → Optimizer
2.	Optimizer → VR-1	Optimizer → OpenFMB(MQTT) → Field Agent → DNP → VR-1 (Manual Mode)

11.4 Use Case Pre-Conditions – UC 3b Peer-to-Peer Volt/Var Control

Pre-Conditions	***Description***
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	OpenFMB pre-configured
3.	Multiple field agents connected and communicating via OpenFMB
4.	Optimizer Pre-configured
5.	Control Portal Pre-configured
6.	RTDS is Active
7.	Network Model with Switchable Devices (2 Circuits)
8.	Tie Switch (Tie SW) is Closed
9.	Cap 1 is Close
10.	Cap 2 is Close
11.	R-1 is Closed
12.	VR-1 is Auto
13.	SW-1 is Closed
14.	Control Portal displays measurement values
15.	R-2 is Closed

12. Use Case 4a – DER Active Power Control

12.1 Use Case Description – UC 4a DER Active Power Control

UC 4a DER Active Power Control

Objective:

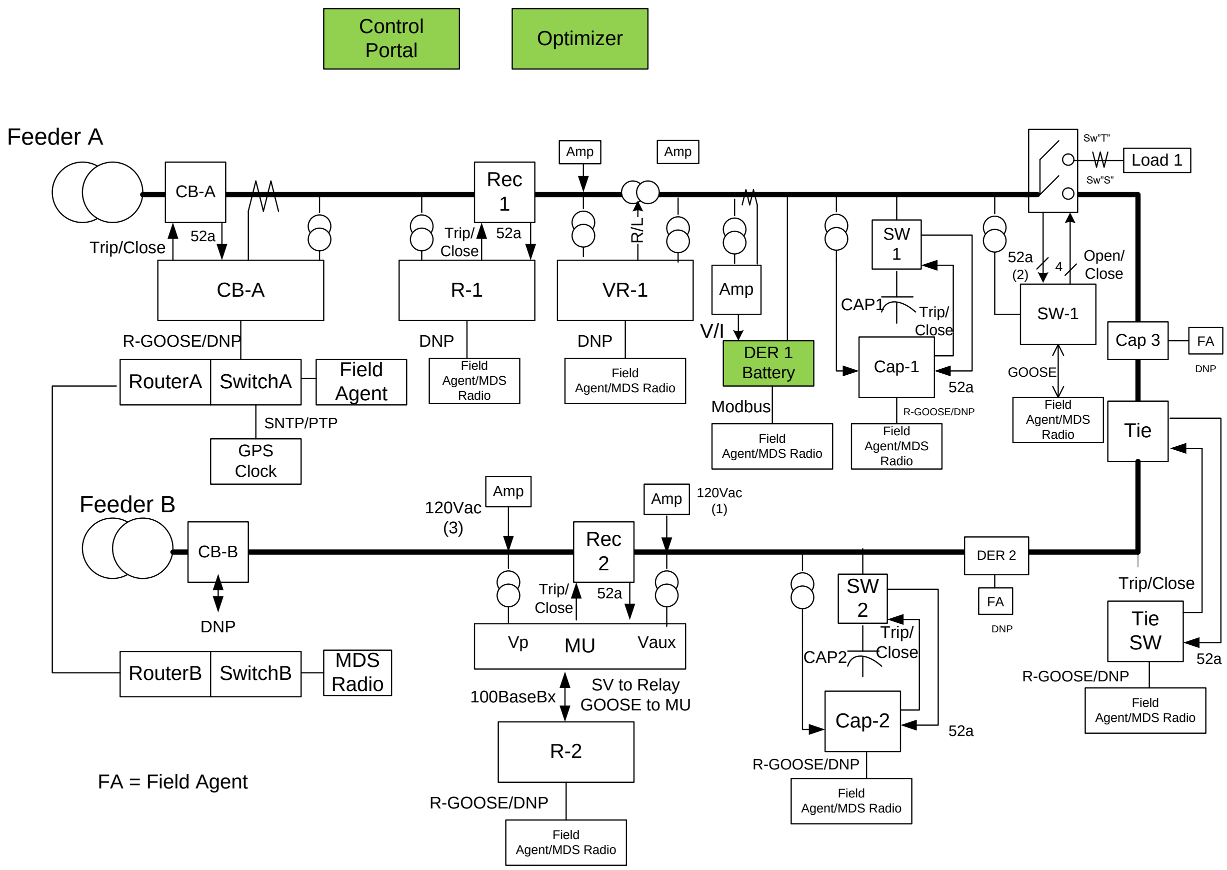
- Demonstrate the capability of OpenFMB using Modbus communication
- Demonstrate the interoperation of traditional IED's and DER using OpenFMB

Description:

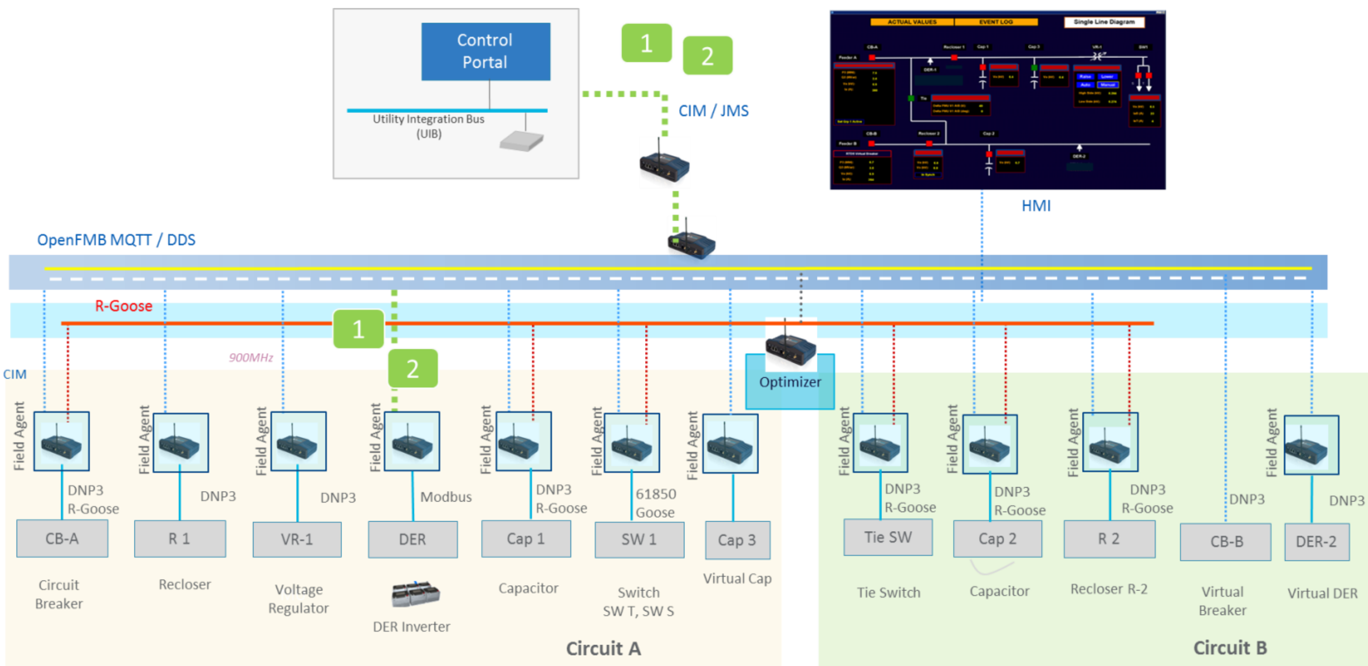
- The DER 1 inverter is to be connected into the RTDS with appropriate digital interface.
- A start command will be sent from the Control Portal to DER 1
- Operator to issue enable set point command. Enter value in the Heartbeat field
- Operator issues Real Power setpoint. Enter value in Active Power field
- Operator issues Reactive Power setpoint. Enter value in Reactive Power field
- Operator issues new High-Level Control Mode – Voltage Droop Reg. (Volts/Watts). Enter value in VoltControlMode field
- Operator issues new High Level Control Mode – Voltage Droop Reg. (Volts/Vars). Enter value in VoltControlMode field
- Test Engineer removes Ethernet connection to DER 1
- Test Engineer to re-connect Ethernet
- Operator issues reset command to DER 1 via Control Portal
- Operator to Open Breaker A and the response of the DER 1 will be recorded.

12.2 Use Case Diagram – UC 4a DER Active Power Control

Logical and IO Diagram



12.3 Use Case Diagram – UC 4a DER Active Power Control



Data Flow	*Data Flow Summary*	*Protocol*
1.	Control Portal → DER 1	Control Portal → OpenFMB(MQTT) → Field Agent → Modbus → DER 1 Inverter → Enable Start
2.	Control Portal → DER 1	Control Portal → OpenFMB(MQTT) → Field Agent → Modbus → DER 1 Inverter → Enable Joint Power/Reactive Power Set-point change
3.	Control Portal → DER 1	Control Portal → OpenFMB(MQTT) → Field Agent → Modbus → DER 1 Inverter → change Modes
4.	Control Portal → DER 1	Control Portal → OpenFMB(MQTT) → Field Agent → Modbus → DER 1 Inverter → Reset command
5.	Control Portal → DER 1	Control Portal → OpenFMB(MQTT) → Field Agent → Modbus → DER 1 Inverter → Enable Stop

12.4 Use Case Pre-Conditions – UC 4a DER Active Power Control

Pre-Conditions	*Description*
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	OpenFMB pre-configured
3.	Multiple field agents connected and communicating via OpenFMB
4.	Optimizer Pre-configured
5.	Control Portal Pre-configured
6.	Network Model with Switchable Devices (2 Circuits)
7.	Tie Switch (TIE SW) is Open
8.	Cap 1 is Close
9.	Cap 2 is Close
10.	R-1 is Closed
11.	VR-1 is Auto
12.	SW-1 is Closed (2 positions)
13.	Control Portal displays measurement values
14.	R-2 is Closed
15.	DER inverter or Simulator has heartbeat
16.	On Power-up of the DER 1 and Field Agent, the following registers shall be WRITTEN as part of initialization via the Control Portal: 40003 – 2 – START (Enter 1 CP Switch Position) 40007 – 2 – RESET 40008 – 2 – Set Voltage Source Inverter – PQ Mode 40009 – 100 – Initial Real Power Set Point 40101 – 256 – Set for Voltage / Watt mode of operation 40010 – 50 – Initial Reactive Power Set Point

13. Use Case 5a – DER on Line / off-line

13.1 Use Case Description – UC 5a DER on Line / off-line

UC 5a DER on Line / off-line

Objective:

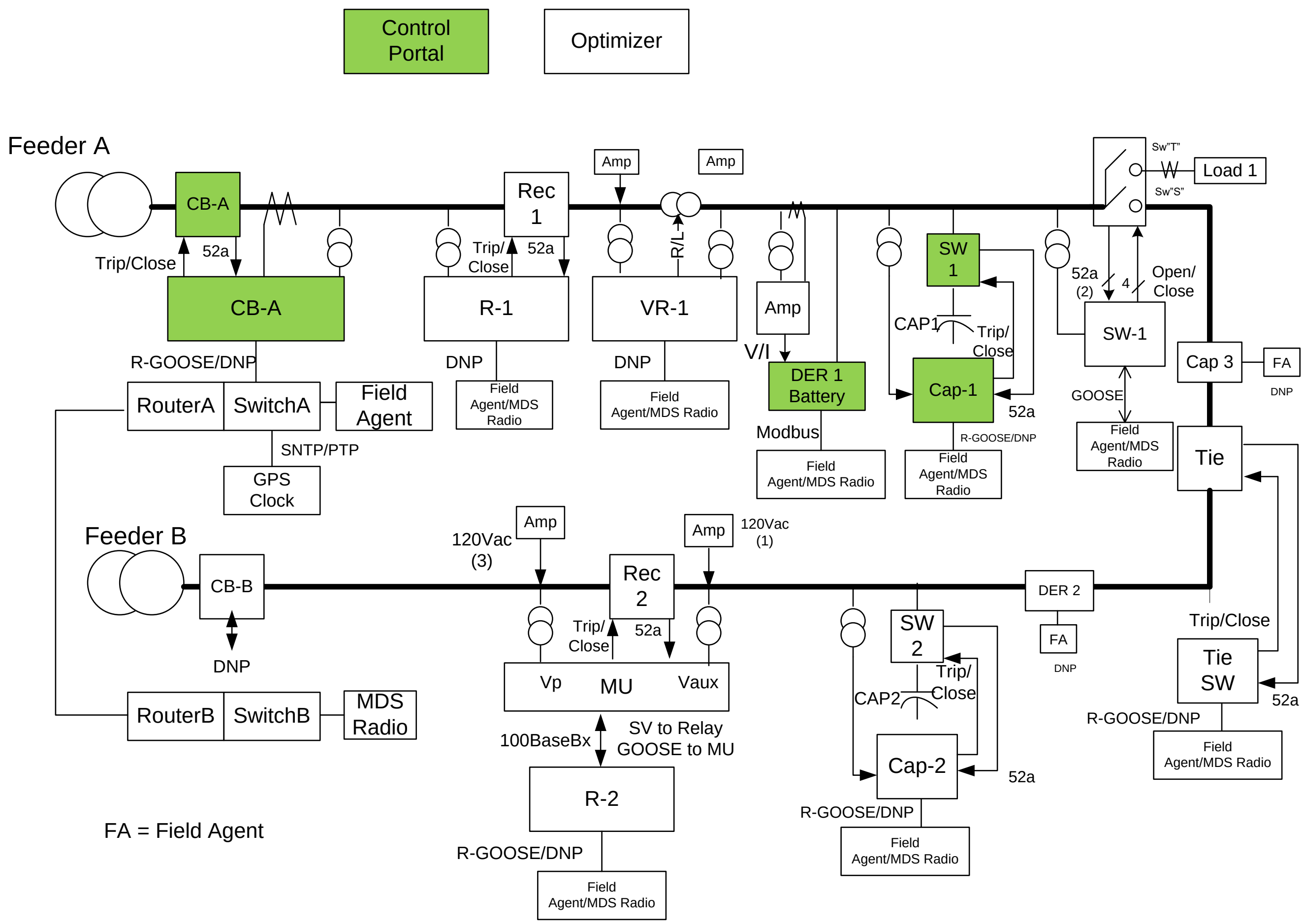
- Demonstrate use of R-Goose to improve system performance by communicating breaker status to DER 1 and thereby over-riding autonomous DER control functions.

Description:

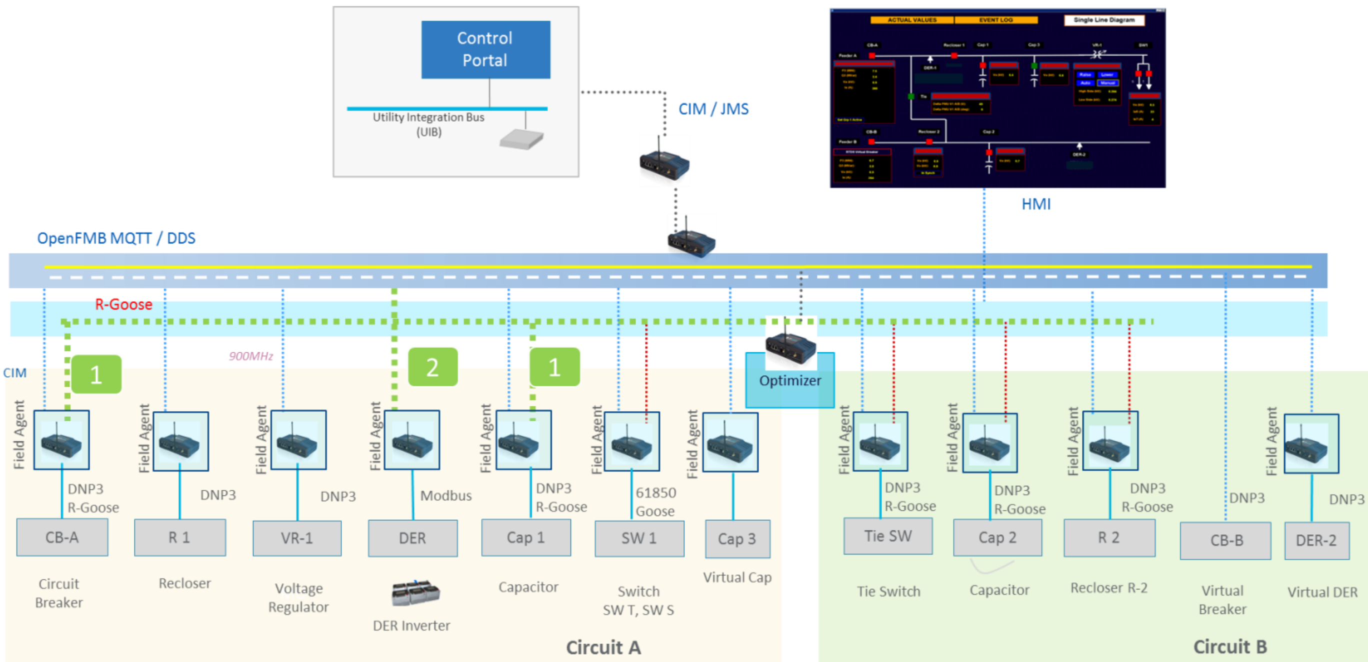
- To demonstrate enhanced DER 1 on-line/off-line via peer to peer
- Pushbutton on CB-A opens CB-A
- Upon detection of Breaker A open, CB-A sends a command to CAP 1.
- CAP 1 operates an output contact to take the DER 1 off-line
- Note: Present implementation of OpenFMB operates at speeds slower than the present disconnect speed of the DER 1.

13.2 Use Case Diagram – UC 5a DER on Line / off-line

Logical and IO Diagram



13.3 Use Case Diagram – UC 5a DER on Line / off-line



Data Flow	*Data Flow Summary*	*Protocol*
1.	CB-A → CAP 1 → DER 1 Inverter	CB-A → R-GOOSE → CAP 1 → Contact Output → DER 1 Inverter

13.4 Use Case Pre-Conditions – UC 5a DER on Line / off-line

Pre-Conditions	***Description***
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	OpenFMB pre-configured
3.	Multiple field agents connected and communicating via OpenFMB
4.	Optimizer Pre-configured
5.	Control Portal Pre-configured
6.	Network Model with Switchable Devices (2 Circuits)
7.	Tie Switch (TIE SW) is Open
8.	Cap 1 is Close
9.	Cap 2 is Close
10.	R-1 is Closed
11.	VR-1 is Auto
12.	SW-1 is Closed (2 positions)
13.	Control Portal displays measurement values
14.	R-2 is Closed
15.	DER inverter or Simulator has heartbeat with RTDS with appropriate amplifier
16.	CB-A is Closed
17.	DER inverter set to maximum zero voltage ride thru

14. Use Case 6a – Enhanced Automatic Feeder re-deployment

14.1 Use Case Description – UC 6a Enhanced Automatic Feeder re-deployment

UC 6a Enhanced Automatic Feeder re-deployment

Objective:

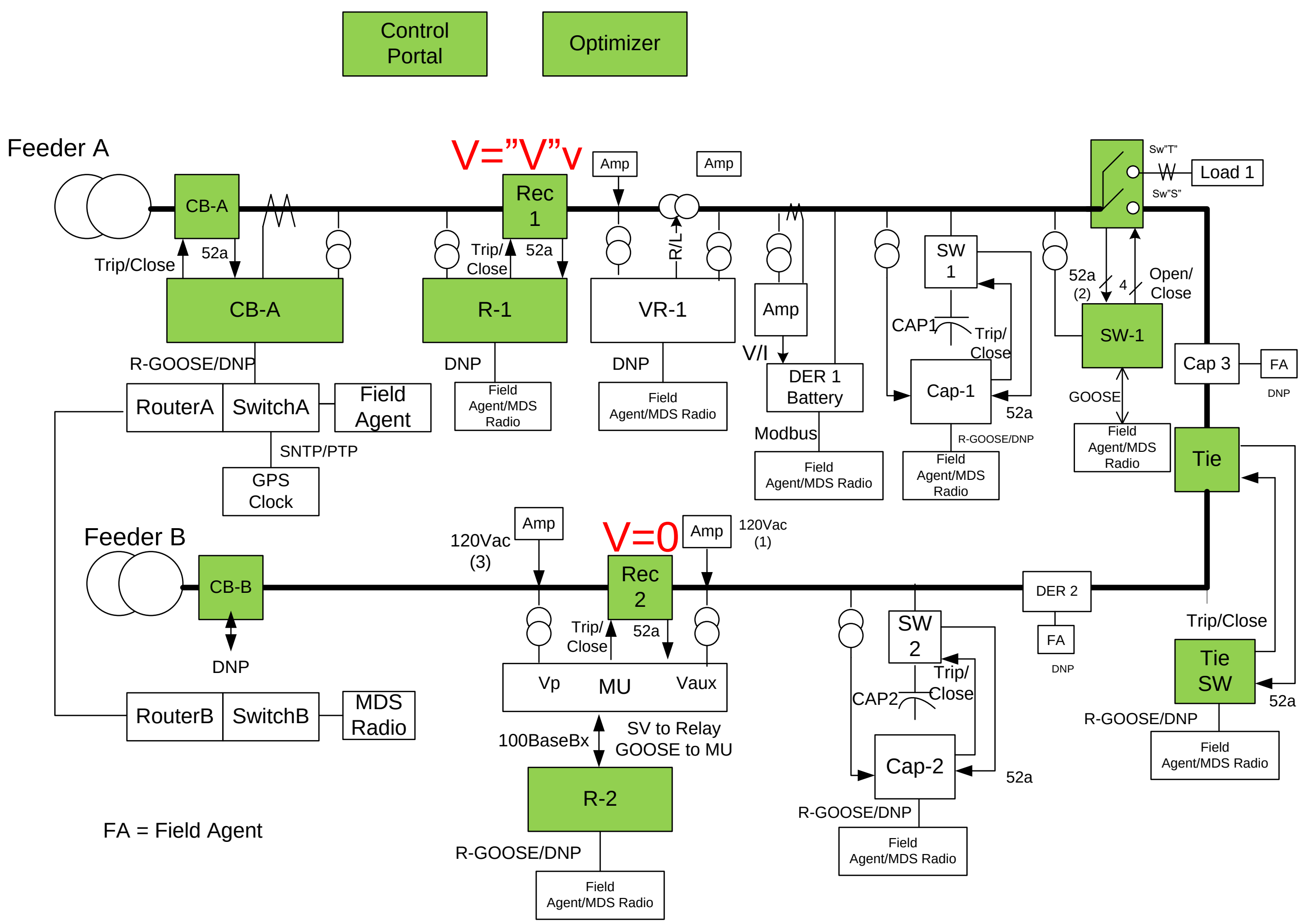
- Demonstrate the mapping of data from GOOSE messages into OpenFMB as well as complex inter-device communication.

Description:

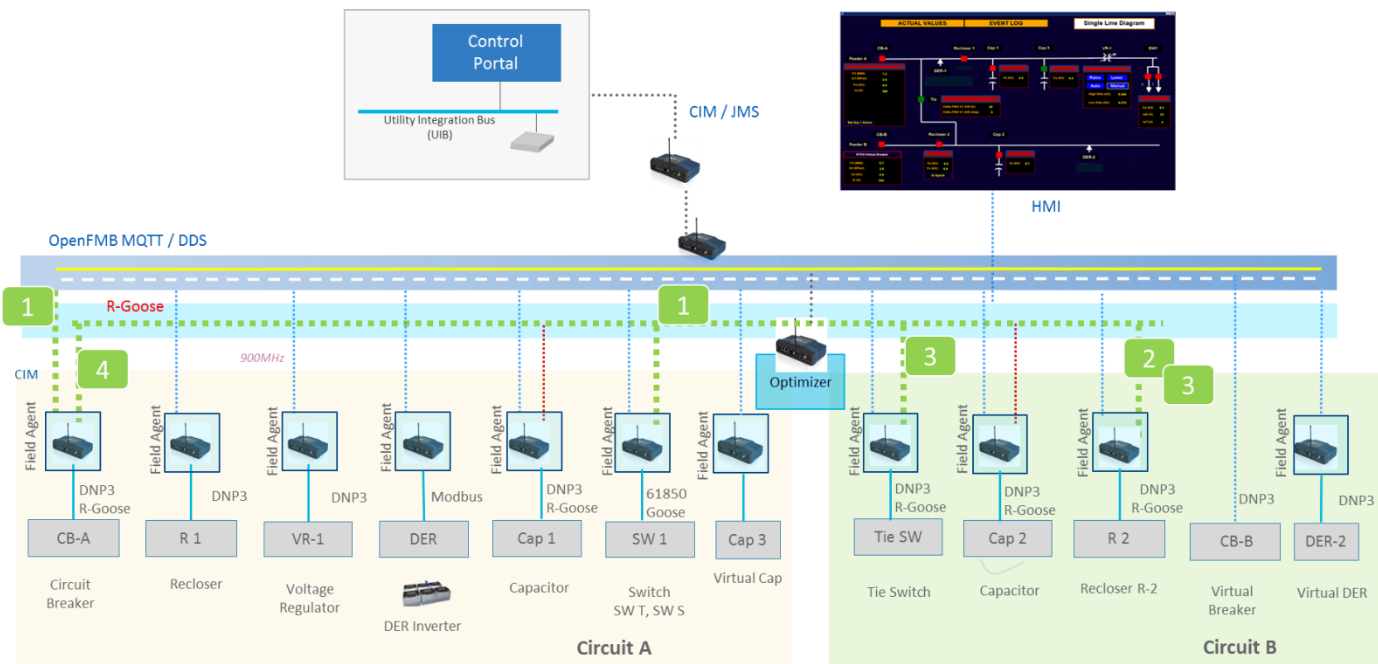
- *Healthy Feeder:*
    - If voltage on the breaker side of Recloser 2 is zero
    - AND there is voltage on Recloser 1 (PT to be located on the Line side of breaker A)
    - AND the feeder is configured for automatic re-deployment (Auto-reconfiguration Push-button on CB-A set to ENABLE)
    - AND the Feeder current (check on Phase A only) is BELOW the re-deployment threshold, the Healthy Feeder A Voltage status bit is set
- *Load Shed:*
    - If voltage on the Breaker side of Recloser 2 is zero
    - AND there is voltage on Recloser 1 AND the feeder is configured for automatic re-deployment (Auto-reconfiguration Push-button on CB-A set to ENABLE)
    - AND the Feeder current (check on Phase A only) is ABOVE the re-deployment threshold, the status bit “Load Shed” (DNP mapped point) is set.
- Message:
    - *If the “Load Shed” DNP point from CB-A is set, an OPEN command is to be sent, via OpenFMB, to OPEN Switch “T” on SW-1 to shed load on the feeder.*
    - *The R-2 on Recloser 2, upon receipt of the “Healthy Feeder A Voltage” status then sends a TRIP command to open Recloser 2*
    - R-2 THEN sends a command to Close the Tie SW – effectively back-feeding the second segment of Feeder B.
    - The CB-A, upon detection of the Tie SW being closed, will change setting groups to Group 2.
- Note: Healthy Feeder A Voltage status is NOT set if the Phase A current is above a user-specified level. A Load needs to be modeled on Switch T; connection to the Tie SW is to be connected to Switch “S”

14.2 Use Case Diagram – UC 6a Enhanced Automatic Feeder re-deployment

Logical and IO Diagram



14.3 Use Case Diagram – UC 6a Enhanced Automatic Feeder re-deployment



Data Flow	*Data Flow Summary*	*Protocol*
1.	CB-B → Open Breaker→ R-2	CB-B → Open Breaker, R-2 voltage = 0
2.	CB-A → R-Goose → R-2 → Healthy Feeder message	CB-A → R-Goose → R-2 → Healthy Feeder Message →Trip Open R-2
3.	R-2 → close Tie SW	R-2 → R-GOOSE → Tie SW
4.	CB-A → OpenFMB → SW-1	CB-A → *"Load Shed"* Open SW T Command (DNP) → OpenFMB (MQTT → Field Agent → OPC UA →61850 Goose message → SW-1 "Open Switch T"
5.	CB-A → Healthy Feeder message → close Tie SW → energize Feeder A	CB-A → R-GOOSE → Tie SW → energize Feeder A
6.	CB-A → change setting group	CB-A → change setting group to 2

14.4 Use Case Pre-Conditions – UC 6a Enhanced Automatic Feeder re-deployment

Pre-Conditions	*Description*
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	OpenFMB pre-configured
3.	Multiple field agents connected and communicating via OpenFMB
4.	Optimizer Pre-configured
5.	Control Portal Pre-configured
6.	Network Model with Switchable Devices (2 Circuits)
7.	Tie Switch (TIE SW) is Open
8.	Cap 1 is Open or Closed
9.	Cap 2 is Open or Closed
10.	R-1 is Closed with Voltage > 0
11.	VR-1 is Auto
12.	SW-1 is Closed (S Switch & T Switch)
13.	Control Portal displays measurement values
14.	CB-B is Closed
15.	CB-A is Closed with Auto Re-deployment enabled
16.	Test Engineer to enable the CB-A Auto Re-deployment
17.	CB-A set over current threshold value IA = X (400 amps)
18.	Var Per Unit Condition = 2.5 MVAR; PU setting = 0.39 = 3.37 MVAR
19.	Voltage “OK” value = 0.9 PU

15. Use Case 7a – Automatic Feeder Re-Close

15.1 Use Case Description – UC 7a Automatic Feeder Re-Close

UC 7a Automatic Feeder Re-Close

Objective:

- Demonstration circuit re-configuration back to normal operating condition

Description:

- Precondition: Breaker B is Open and Recloser 2 is Open.

UC 7a -1 Inside the Limit

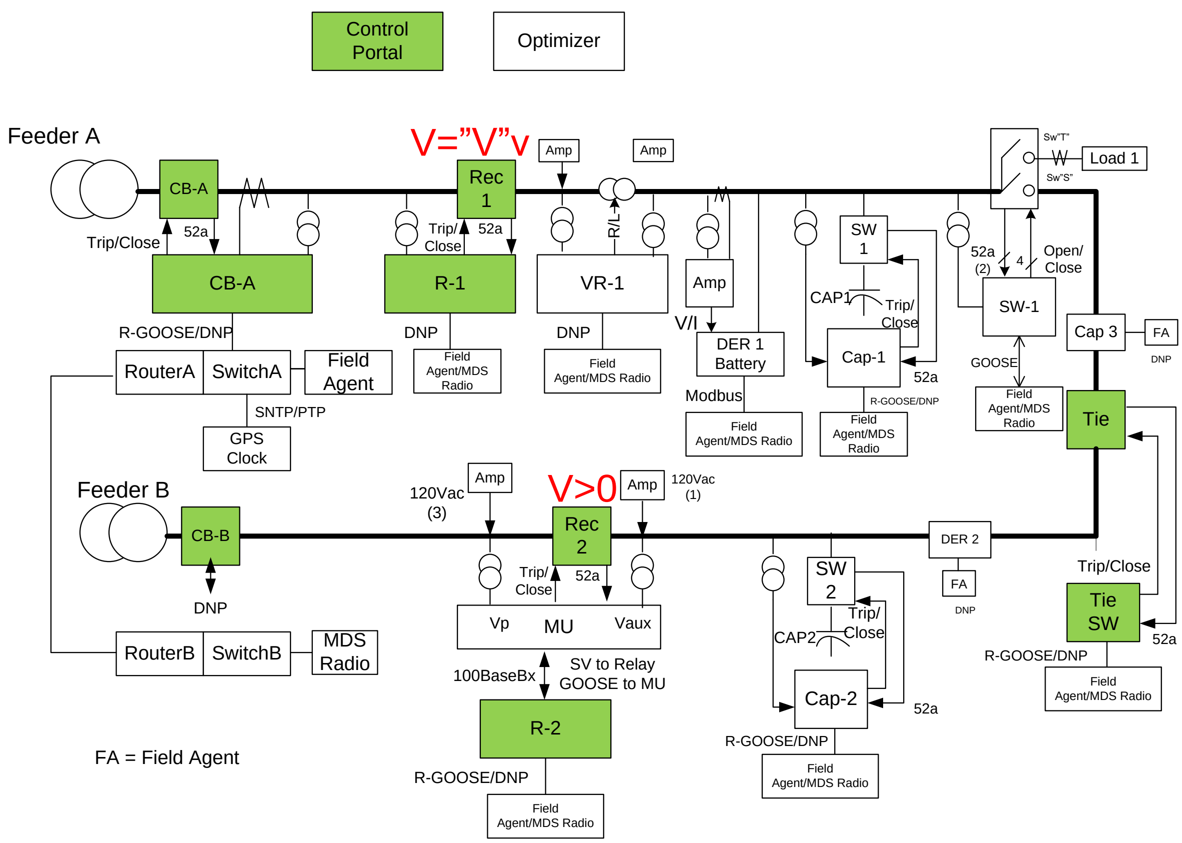
- Breaker B is then closed by RTDS / HMI – placing Voltage on the Breaker side of Recloser 2.
- Voltage is detected on both sides of the R-2 and the phase angle of the voltage across the recloser is less than 30 degrees (as measured by R-2)
- THEN reclose R-2 and Open the Tie SW from R-2.
- The CB-A identifies that the Tie SW is now open and changes back to the setting group 1.

UC 7a -2 Outside the Limit

- Breaker B is then closed by RTDS / HMI – placing Voltage on the Breaker side of Recloser 2.
- Voltage is detected on both sides of the R-2 and the phase angle of the voltage across the recloser is = 45 degrees
- Tie SW - measure phase Angle (RTDS observes phase angle) Verify Sync check.
- Recloser 2 (R-2) status fails to close

15.2 Use Case Diagram – UC 7a Automatic Feeder Re-Close

Logical and IO Diagram



15.3 Use Case Diagram – UC 7a Automatic Feeder Re-Close (Use Case Diagram & Data Flow Summary redacted due to IP confidentiality concerns).

15.4 Use Case Pre-Conditions – UC 7a Automatic Feeder Re-Close

Pre-Conditions	*Description*
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	OpenFMB pre-configured
3.	Multiple field agents connected and communicating via OpenFMB
4.	Optimizer Pre-configured
5.	Control Portal Pre-configured
6.	Network Model with Switchable Devices (2 Circuits)
7.	Tie Switch (TIE SW) is Closed
8.	Cap 1 is Open or Closed
9.	Cap 2 is Open or Closed
10.	R-1 is Closed
11.	VR-1 is Auto
12.	SW-1 is Closed (2 positions)
13.	Control Portal displays measurement values
14.	R-2 is Open
15.	CB B is Open
16.	CB A is Closed

16. Use Case 8a – Sample Value Use Cases (Documentation only)

16.1 Use Case Description – UC 8a Sample Value Use Cases (Documentation only)

UC 8a Sample Value Use Cases
Objective:

- Demonstrate the high-speed transmission of sample values as to further develop communication requirements for OpenFMB

UC 8a Sample Value Use Cases (Documentation only)

- The measurement and transmission of Voltage and Current values from field equipment is known as Sample Values. Sample Values (SV) typically require high sample rates in the range of 3000 to 96,000 samples per second. Additionally, the device creating the Samples (known as the Merging Unit) can be located several kilometers away. IEC61850 introduced the concept of Sample Values as a digital interface to Optical Current and Voltage sensors as well as application-specific circumstances where remote location of Voltage and Current sensors is required/desirable. The 61850 standard addresses issues such as data synchronization and phase correction. Given the high bandwidth and low latency constraints of such data, further study of its applicability to OpenFMB is needed.
- Note: extend the write-up to include RSV documentation

17. Use Case 8b – Synchrophasors via R-Goose

17.1 Use Case Description – UC 8b Synchrophasors via R-Goose

UC 8b Synchrophasors via R-Goose
Objective:

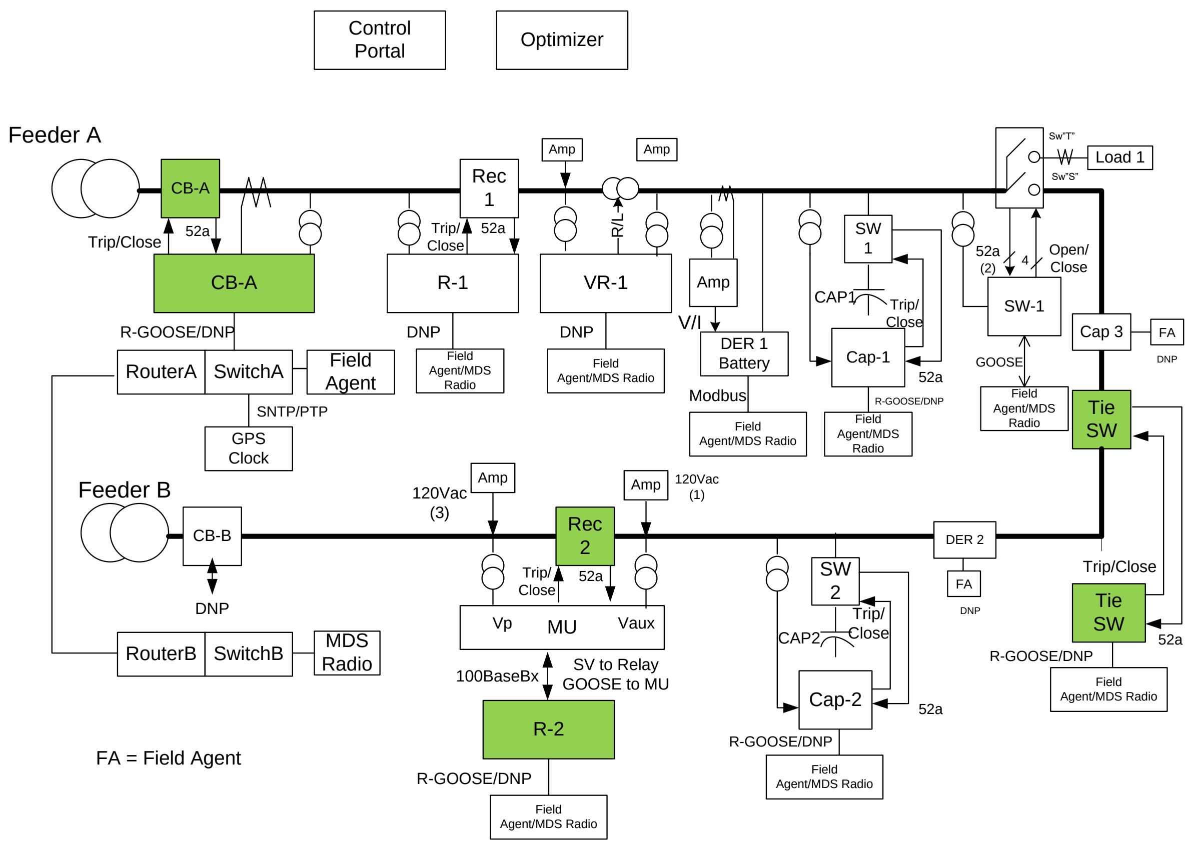
- Demonstrate the pub/sub of high speed data (e.g. synchrophasors) via routable GOOSE and evaluate the incorporation into OpenFMB standards.

Description:

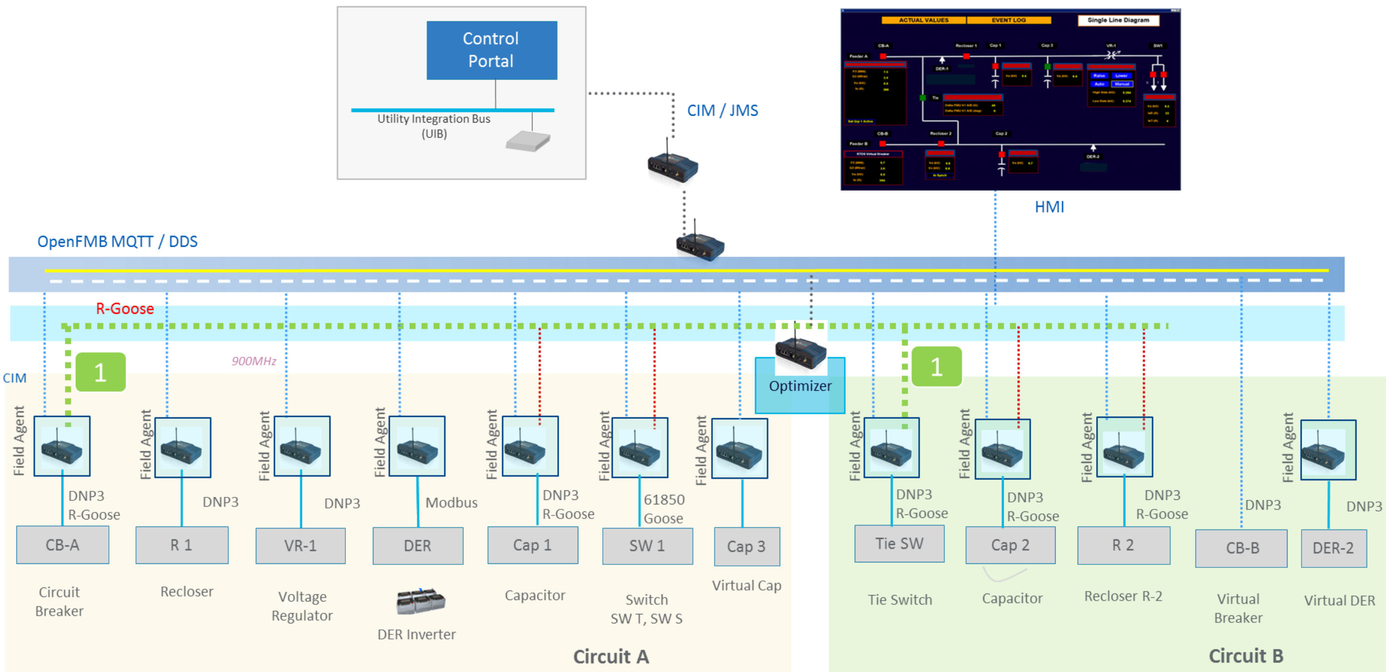
- Synchrophasors (V1 Magnitude and Angle) are to be mapped into Generic Analog 61850 data objects in CB-A and R-2 and then included in R-GOOSE messages.
- R-GOOSE reception by Tie SW.
- Tie SW commutes magnitude difference and angle difference

17.2 Use Case Diagram – UC 8b Synchrophasors via R-Goose

Logical and IO Diagram



17.3 Use Case Diagram – UC 8b Synchrophasors via R-Goose



Data Flow	***Data Flow Summary***	***Sequence***
1.	CB-A & R-2 send Synchrophasor data to Tie SW	F60 → R-Goose → Tie SW

17.4 Use Case Pre-Conditions – UC 8b Synchrophasors via R-Goose

Pre-Conditions	*Description*
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	Network Model with Switchable Devices (2 Circuits)
3.	Tie Switch (TIE SW) is Open
4.	Cap 1 is Open or Closed
5.	Cap 2 is Open or Closed
6.	R-1 is Closed
7.	VR-1 is Auto
8.	SW-1 is Closed (2 positions)
9.	Control Portal displays measurement values
10.	R-2 is Closed
11.	CB B is Closed
12.	CB A is Closed

18. Use Case 9a – Dynamic Subscription (Documentation Only)

18.1 Use Case Description – UC 9a Dynamic Subscription (Documentation)

UC 9a Dynamic Subscription
Objective:

- Identify the requirement for dynamic subscription for all messaging protocols for incorporation into OpenFMB standards.

Description:

- In the scenario when Feeder A and Feeder B are separated, there is no need to share messages between them. Once the Tie SW is closed, it becomes desirable for the devices on Feeder A to be able to "subscribe" to information from devices on the "extended" line.
- For this purpose, it is to be noted that Dynamic Subscription becomes a need in this Use case.
- Additionally, the definition of the data objects from the newly subscribed devices may be needed – especially if there had been setting changes in any of the newly-subscribed devices.

19. Use Case 10a – End-to-End Security (Documentation Only)

19.1 Use Case Description – UC 10 End-to-End Security (Documentation)

UC 10a End-to-End Security
Objective:

- Identify the requirement for end to end security into OpenFMB standards.

Description:

- When communicating device-to-device in the field, end-to-end secure communications are required.
- End-to-end security should be developed that addresses authentication, authorization, access control, confidentiality, integrity, non-repudiation, availability, and accountability.

20. Use Case 11a – Administration of Devices using OpenFMB

20.1 Use Case Description – UC 11a File transfer

UC 11a File transfer
Objective:

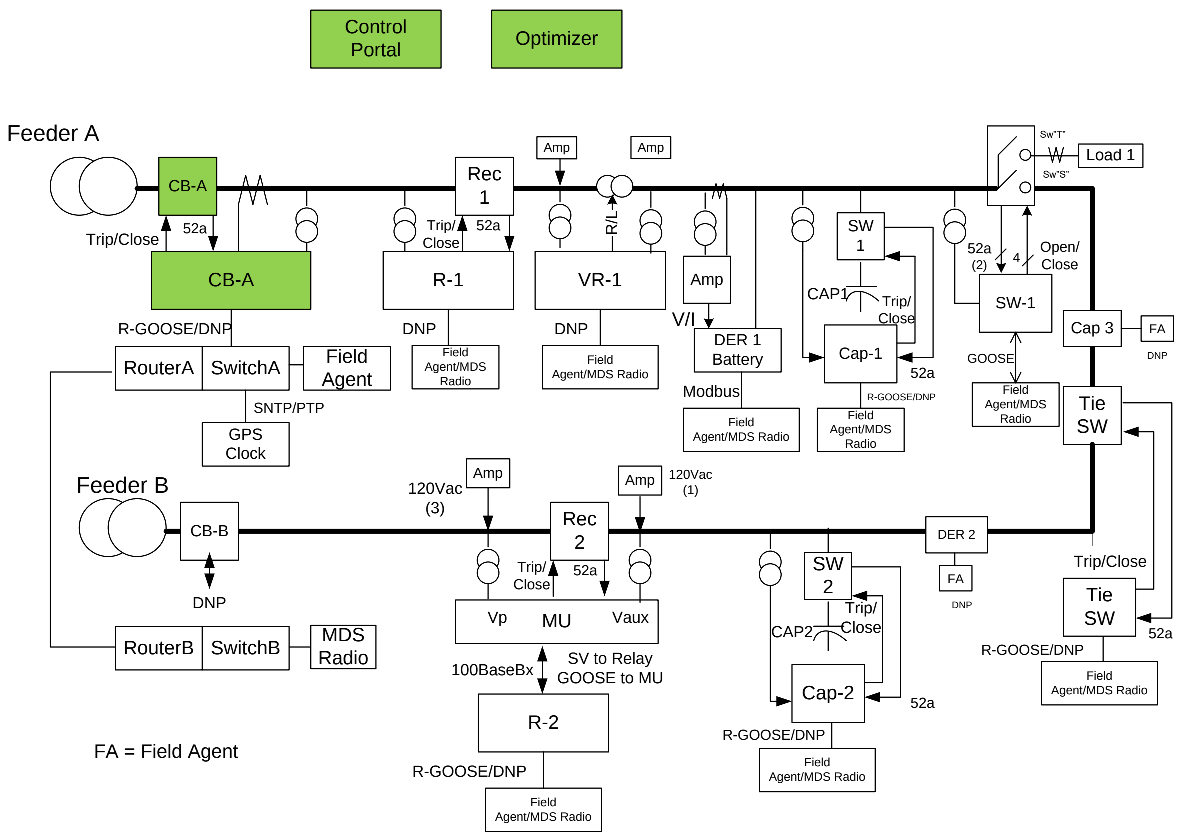
- Demonstrate file transfer using OpenFMB

Description:

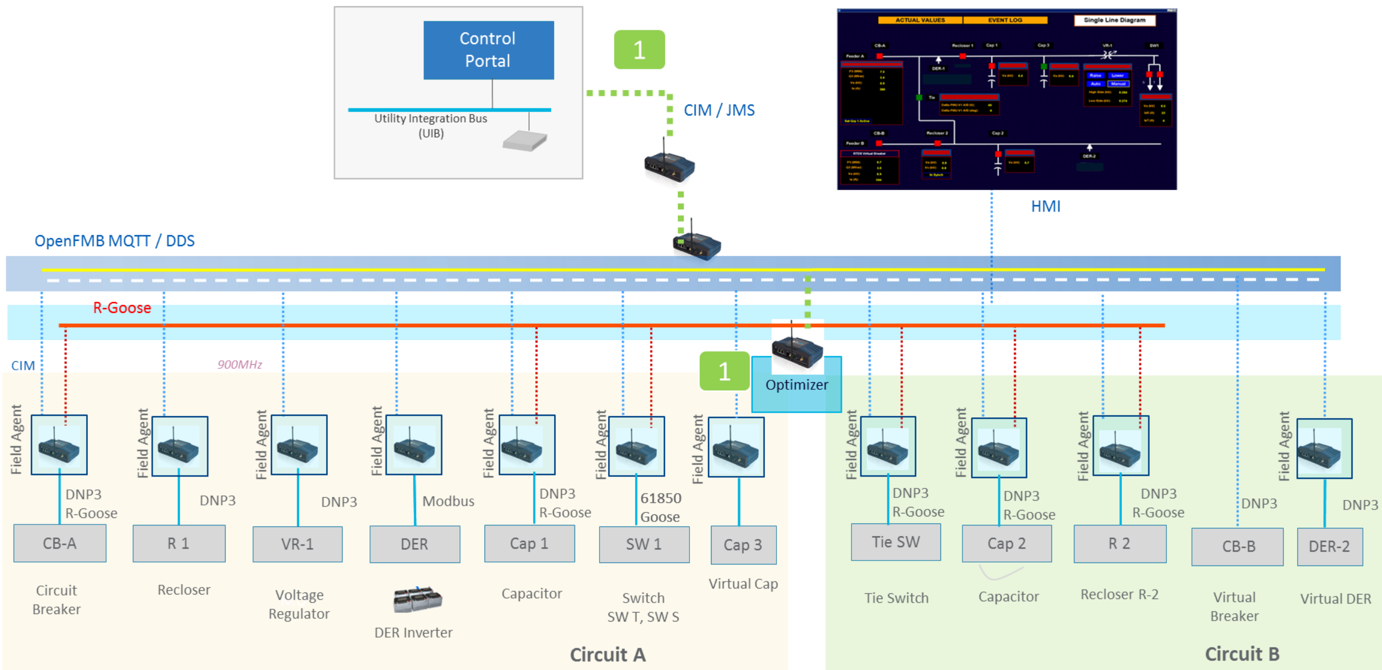
- To demonstrate the transfer of a settings file, a file will be transferred from the Administration Node to a Field Agent (OpenFMB Adapter). This file will be of a size representative of a settings file - ~10 KB. Settings files may also be unique to each OpenFMB node.

20.2 Use Case Diagram – UC 11a File transfer

Logical and IO Diagram



20.3 Use Case Diagram – UC 11a File transfer



Data Flow	*Data Flow Summary*	*Sequence*
1.	Control Portal → CB-A Optimizer	Control Portal → CB-A Optimizer

20.4 Use Case Pre-Conditions – UC 11a File transfer

Pre-Conditions	*Description*
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	OpenFMB pre-configured
3.	Multiple field agents connected and communicating via OpenFMB
4.	Optimizer Pre-configured
5.	Control Portal Pre-configured
6.	Network Model with Switchable Devices (2 Circuits)
7.	Tie Switch (TIE SW) is Closed
8.	Cap 1 is Open or Closed
9.	Cap 2 is Open or Closed
10.	R-1 is Closed
11.	VR-1 is Auto
12.	SW-1 is Closed (2 positions)
13.	Control Portal displays measurement values
14.	R-2 is Closed
15.	CB B is Closed
16.	CB A is Closed
17.	CB-A running Optimizer

20.5 Use Case Description – UC 11b Firmware

UC 11b Firmware (Documentation Only)
Objective:

- Document Firmware transfer

Description:

- To demonstrate the transfer of a firmware image, a file will be transferred from the Administration Node to a Field Agent (OpenFMB Adapter). This file will be of a size representative of a firmware image - ~10 MB.
- It should be highlighted in the report that firmware images will need to have various security characteristics that may be unique to firmware such as manufacturer signing. Firmware images may also be unique to each OpenFMB node.
- Note: File size presently limited by file availability

20.6 Use Case Description – UC 11c Provisioning (Documentation Only)

UC 11c Provisioning (Documentation Only)
Objective:

- Document the requirement to provision field devices using OpenFMB

Description:

- To set up an OpenFMB network, the secure provisioning of OpenFMB nodes is critical. Each OpenFMB node will need to have its security credentials verified with the Administration Node. Various settings will also need to be communicated relating to both the node's network and the node's application functionality. Initial subscriptions to other OpenFMB nodes will also need to be created
- Provide example of documentation of provisioning of settings file for a Cap Bank similar to CAP 1 or CAP 2.

21. Use Case 12a – Operational Data File transfer using OpenFMB

21.1 Use Case Description – UC 12a Operational Data File transfer using OpenFMB

UC 12a File transfer (Documentation Only)
Objective:

- Demonstrate file transfer using OpenFMB

Description:

- Demonstrate file transfer from an Administration Node to other nodes through OpenFMB (MQTT) – field agent-to-field agent.

- Currently, OpenFMB does not define file transfer. In the future, OpenFMB may choose to Use another protocol better suited for file transfer (e.g., SFTP) as pub/sub protocols are not typically used for large, point-to-point, file transfers. Further, individual settings and firmware is likely not to be broadcast as security images, configuration, and other aspects are likely to be unique to each node. These are critical points that need to be clearly articulated in the final document.

- Note: Refer to Use Demonstration Use Case 11a

22. Use Case 13a – OpenFMB using DDS

22.1 Use Case Description – UC 13a OpenFMB using DDS

UC 13a OpenFMB using DDS
Objective:

- Demonstrate OpenFMB using DDS

Description:

- The Tie SW is set as the one of the DDS nodes.
- The Tie SW gets the data (measurement value) from DNP3 adaptor and publishes the data on the DDS virtual FMB
- Another DDS node subscribes to the data.
- Once the data is received, the data is published in the Audit Log

Appendix B. Test Cases

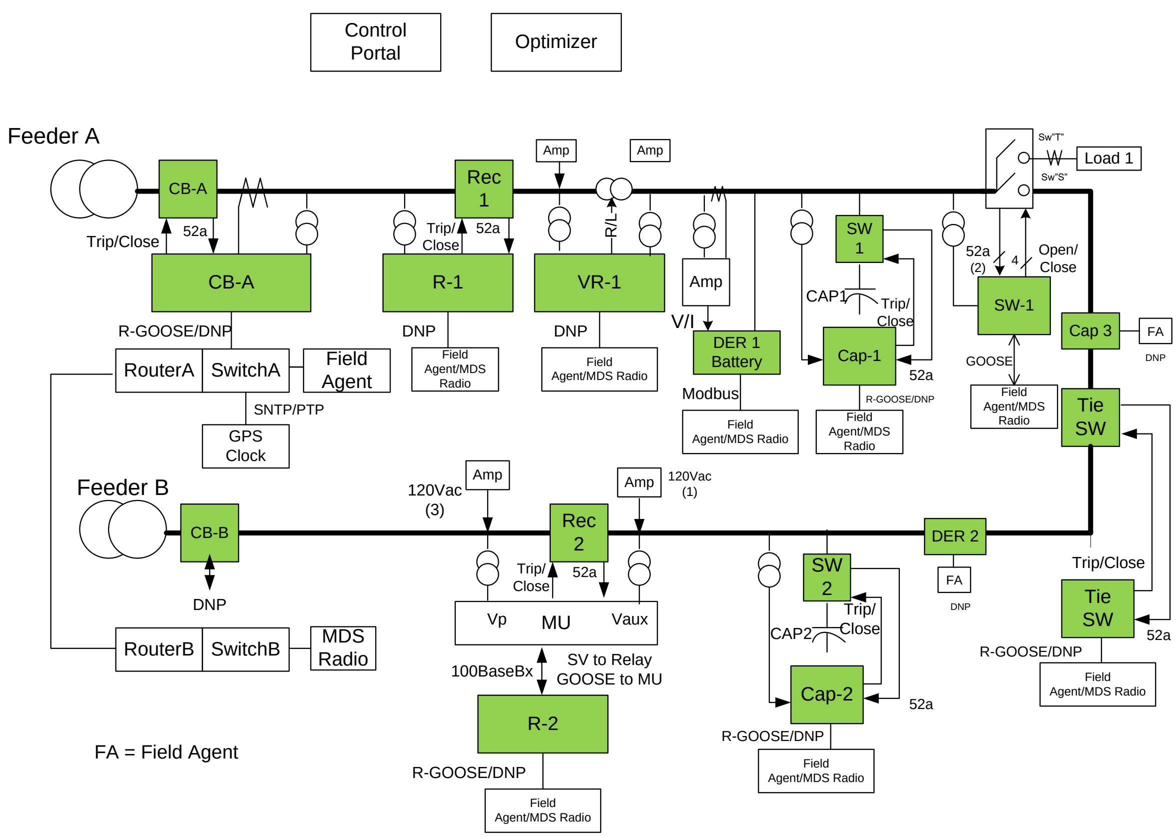
Test Case Contents:

1 Introduction

The purpose of this section is to specify test procedures and steps for the OpenFMB test cases that were undertaken as part of the pre-commercial demonstration project. The test cases intended to demonstrate the functional and non-functional test cases for the OpenFMB setup used for testing at SDG&E's laboratory.

2 Test Case Reference Architecture

2.1 Reference Architecture – Figure 1



2.2 Reference Architecture – Figure 1 Device Names

Note: Device Names and abbreviations

Device Description	***Device Abb.***
Vendor A - Circuit Breaker A	CB-A
Vendor A - Capacitor 1	Cap 1
Vendor A - Capacitor 2	Cap 2
Vendor A - Tie Switch	Tie SW
Vendor A - Recloser 2	R-2
Vendor A - Virtual Capacitor 3	Cap 3
Vendor A - Virtual DER	Der 2
Vendor B Recloser 1	R-1
Vendor B Voltage Regulator	VR-1
Vendor B Load Switch	SW-1
Vendor C DER	DER 1
Vendor B Circuit Breaker B	CB-B

3 Test Case 1a - OpenFMB Connection to Relays & Virtual DER / Cap Bank

3.1 Test Case Description - UC 1a OpenFMB Connection to Relays & Virtual DER / Cap Bank

UC 1a: OpenFMB Connection to Relays and Virtual DER / Cap Bank

Objective:

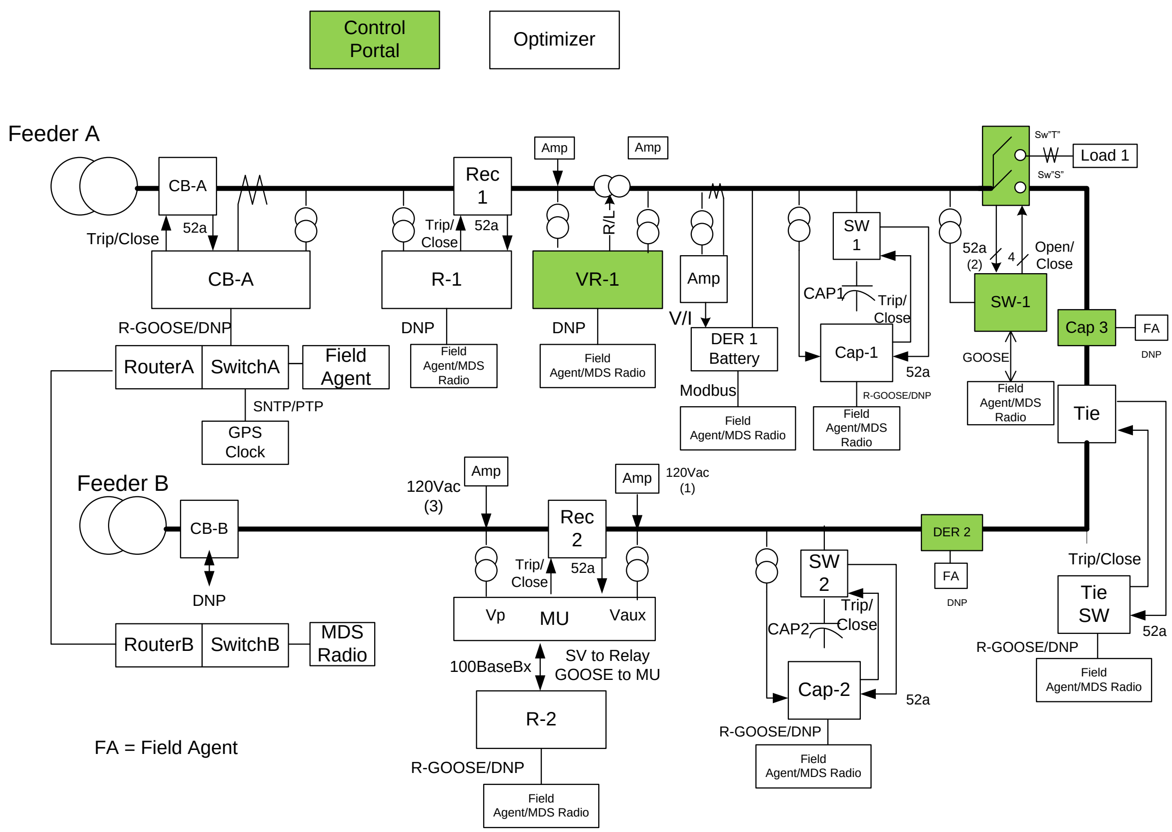
- Demonstrate the use of OpenFMB to communicate from a Control Portal to a field device showing:
    - Status – measurement values
    - Control – change status

Description:

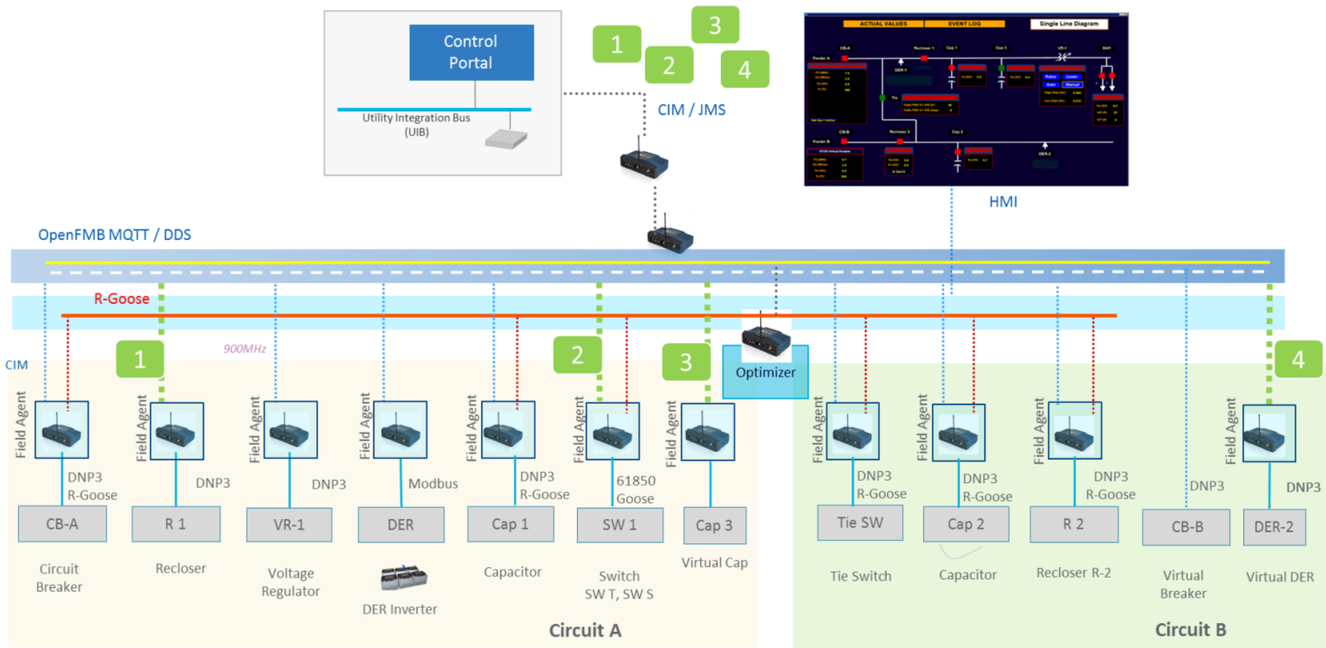
- Operation of Recloser 1 (R-1) (Open/Close) and Voltage measurements are to be made through OpenFMB messaging to the Recloser 1 (R-1) relay.
- Control and status of Switch 1 SW-1 are to be demonstrated from the Control Portal through OpenFMB to the Switch (SW-1).
- Control and Status of the Virtual DER (DER 2)
- Control and Status of the Virtual Cap Bank (Cap 3)

3.2 Test Case Diagram - UC 1a OpenFMB Connection to Relays & Virtual DER / Cap Bank

Logical and IO Diagram



3.3 Test Case Diagram - UC 1a OpenFMB Connection to Relays & Virtual DER / Cap Bank



Data Flow	*Data Flow Summary*	*Protocol*
1.	Control Portal (CP) → Field Agent → RECLOSER 1 (R-1)	CP →OpenFMB(MQTT) → DNP → RECLOSER 1 (R-1)
2.	Control Portal (CP) → Field Agent → Switch (SW-1)	CP →OpenFMB(MQTT) → DNP → Switch (SW-1)
3.	Control Portal (CP) → Field Agent → Virtual DER (DER 2)	CP →OpenFMB(MQTT) → DNP → Virtual DER (DER 2)
4.	Control Portal (CP) → Field Agent → Virtual Cap Bank (Cap 3)	CP →OpenFMB(MQTT) → DNP → Virtual Cap Bank (Cap 3)

3.4 Pre-Conditions - UC 1a OpenFMB Connection to Relays & Virtual DER / Cap Bank

Pre-Conditions	***Description***
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	OpenFMB pre-configured
3.	Multiple field agents connected and communicating via OpenFMB
4.	Optimizer Pre-configured
5.	Control Portal Pre-configured
6.	RTDS is Active
7.	Network Model with Switchable Devices (2 Circuits)
8.	Tie Switch is Open
9.	Cap 1 is Open
10.	Cap 2 is Open
11.	R-1 is Closed
12.	VR-1 is Auto Mode
13.	SW-1 is Closed (2 positions)
14.	CB-A is Closed
15.	CB-B is Closed
16.	On Power-up of the Virtual DER and Field Agent, the following registers shall be WRITTEN as part of initialization OR via the Control Portal: 40007 – 2 – RESET 40008 – 2 – Set Voltage Source Inverter – PQ Mode 40101 – 256 – Set for Voltage / Watt mode of operation 40009 – 100 – Initial Real Power Set Point 40010 – 50 – Initial Reactive Power Set Point

3.5 Test Steps - UC 1a OpenFMB Connection to Relays & Virtual DER / Cap Bank

Steps	***Description***	***Acceptance Criteria***	***Pass / Fail***
#	*Step Description*	*Describe Acceptance Criteria*	*Pass (P) / Fail (F)*
1.	Start Control Portal	Check the Control Portal & logs to verify CP is running	P
2.	Start Field Agents	Check the log and verity Field Agents are up running. The measurement values shall be published and have values.	Measurement values are displayed
3.	Insert ALL GE devices • CB-A RTDS, Analog, Status Verified • Recloser R-2 – RTDS, Analogs (V, No I, No P); Status Verified • We verified Tie SW using DNP3 through control portal. • CAP 2 – RTDS, Analog, Status Verified. • CAP 1 – RTDS, Analog, Status verified		P
4.	Monitor measurement values on R-1	Measurement value = voltage reading RTDS, Analog (P,V,Q,I), Status verified.	P
5.	Control Portal send R-1 Open command	R-1 = Open	P
6.	Monitor measurement values on SW-1	Measurement value = voltage reading	P
7.	Control Portal send SW Open command	SW-1 = Open	F – 3rd party vendor software issue
8.	Monitor measurement values on Virtual DER 2	Measurement value = status	
9.	Control Portal exercise range of commands	DER 2 Commands: 40007 – 2 – RESET 40008 – 2 – Set Voltage Source Inverter – PQ Mode 40101 – 256 – Set for Voltage / Watt mode of operation 40009 – 100 – Initial Real Power Set Point 40010 – 50 – Initial Reactive Power Set Point	 P F F P P
10.	Monitor measurement values on Virtual Cap Bank (Cap 3)	Validate Measurement status values	P
11.	Control Portal sends Control values to Virtual Cap Bank	Virtual Cap Bank Control = Open/Close	F

Steps	*Description*	*Acceptance Criteria*	*Pass / Fail*
12.	OpenFMB communication to VR-1 is possible through control portal. The VR-1 configuration supports switching modes from manual to auto.	Measure Value Verification Status Verification Control mode verification Voltage Regulation (local) verification	MV Pass, Status Pass, Control Mode Pass,

3.6 Test Case Results - UC 1a OpenFMB Connection to SEL Relays & Virtual DER / Cap Bank

Operation:

In this first use case, communication to ALL relays was demonstrated via OpenFMB through the Control Portal. The Control Portal is an auto-generated HMI – the construction of which is based on the Common Information Model or CIM. The team was given the physical layout of two feeders on the SDG&E system which was converted to a geographic layout – on top of GOOGLE maps. Figure 1a-1 below shows an image of the Control Portal.

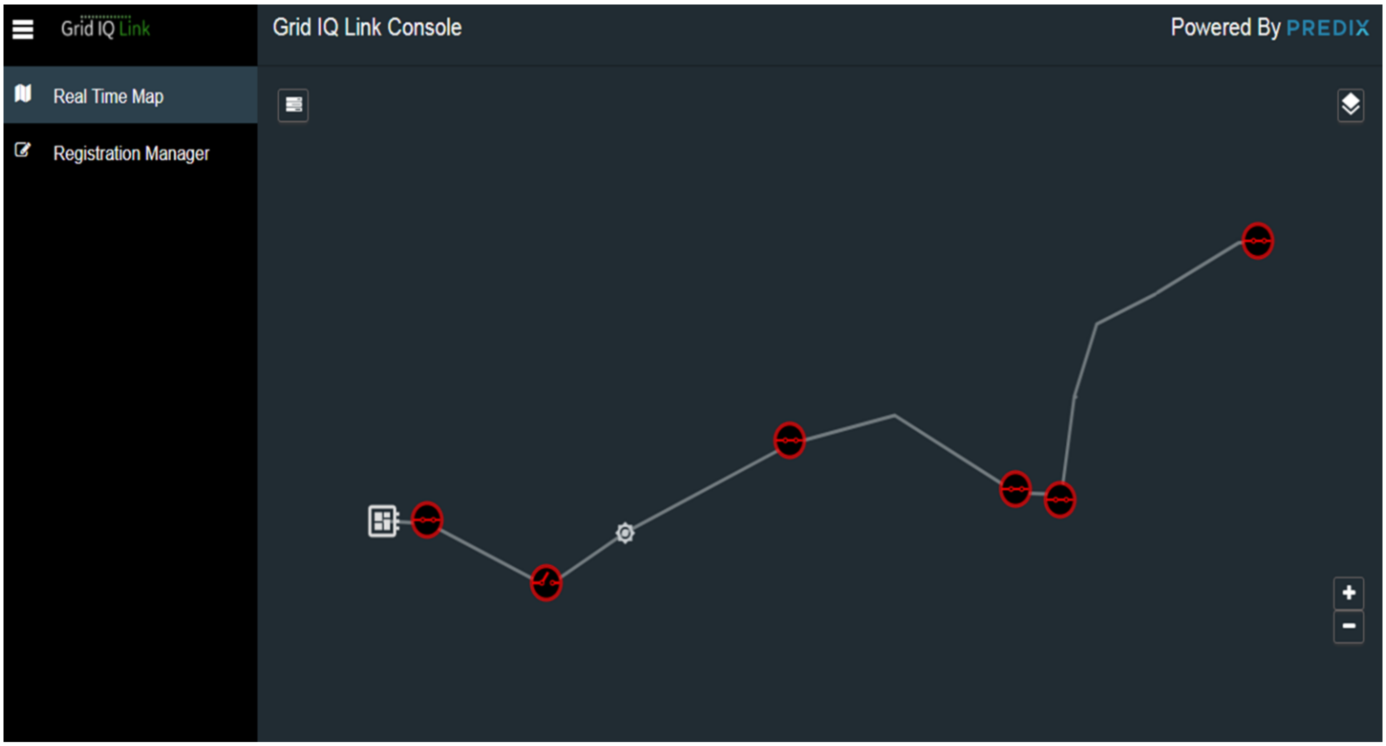


Figure 1a-1 – Control Portal

Line Layout from the Control Portal

From the control portal, a user could select a device with which to communicate. The available made available through the Control Portal was a function of the data made available either though DNP or Modbus. A GOOSE interface was attempted but due to 3rd party SW issues, was unable to be demonstrated at the time of this writing. Additionally, there were 2 mapping issues with the interface to the Distributed Energy Resource device and to the circuit switcher – otherwise, the ability to monitor and control all other devices was demonstrated.

The figure below shows an example of a device's available data and controllable items. In general, voltages, currents, Watts, Vars, status, and Control was available through the Control Portal.

Figure 1a-2
Typical Control Portal Device Data Display

Communication Observations:

Communication to the various network devices was split between direct communication at 100MB Ethernet for substation-connected devices and 500kb - 900MHz radio for the field connected devices. Variation in performance between the two networks was negligible.

Communication to the Switch controller was targeted to be OpenFMB to OPC-UA to GOOSE to the switch controller. Issues with the GOOSE to OPC-UA SW modules (including 3rd party SW) precluded implementation of a complete solution. Elements of the available data were visible on the GOOSE collection SW, however, integration between the OPC-UA Client and server proved to be problematic and unable to be established.

Of note, however, was the fact the messages from the Switching device over GOOSE were multicast on change of state and readily readable through the observation window on the 3rd party GOOSE capture SW.

OpenFMB Gaps:

In as much as the integration of data into OpenFMB on the project was performed through protocol translation and the mapping of data into the Common Information Model (CIM) XML format, there was a sizable increase in data packet size from the base message (e.g. – 10 bytes in Modbus) to maybe 5000 bytes when migrated into CIM and OpenFMB – most of which was the mapping into CIM XML. OpenFMB needs to evaluate the model of simple Datasets being carried by the appropriate OpenFMB protocol with Out of Band Dataset configuration.

Recommendations:

The items on the Control Portal were not labeled in the top-level view making discovery of circuit names and devices a challenge. Additionally, the device names on the exploded view were not representative of the actual devices being monitored. Implementation of this technology going forward needs to incorporate a naming convention to facilitate device identification. As Future versions of the Control Portal should consider on-screen names and Tool Tips that can provide additional information to a user.

Operation of the controls needs to be more user-friendly. Use of the words "Open" and "Close" and "Raise" and "Lower", etc. need to be incorporated into the Control Portal language.

Timing of the open and close function through OpenFMB was timed via stop watch. Going forward, it would be expected that a Sequence of Events recorder would be embedded into the various elements of the communication system so that not only end-to-end but also link latency could be measured.

4 Test Case 2a - Var Control

4.1 Test Case Description – UC 2a Var Control

UC 2a: Var Control

Objective:

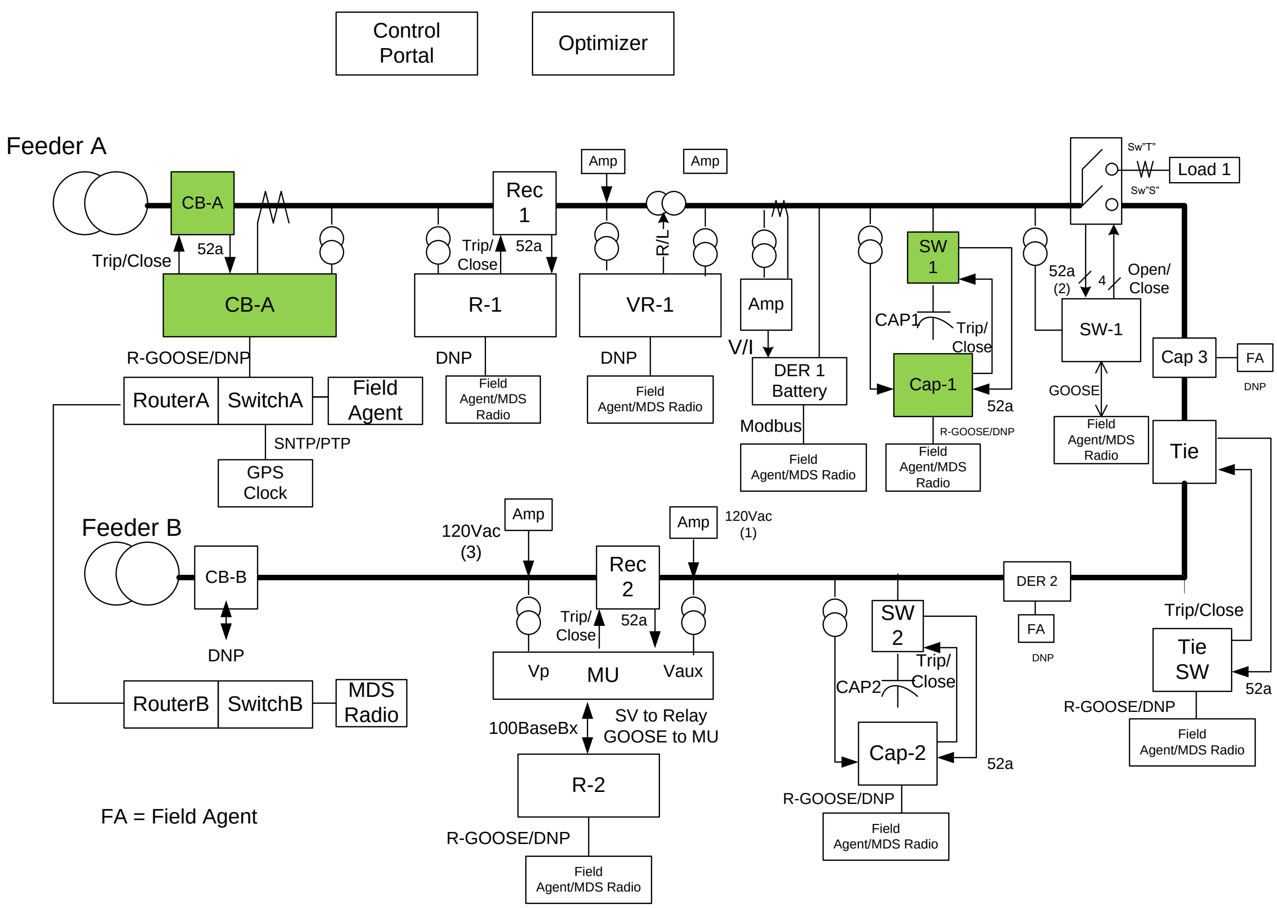
- Evaluate R-GOOSE as an alternative Pub-Sub protocol under the OpenFMB standard / framework.

Description:

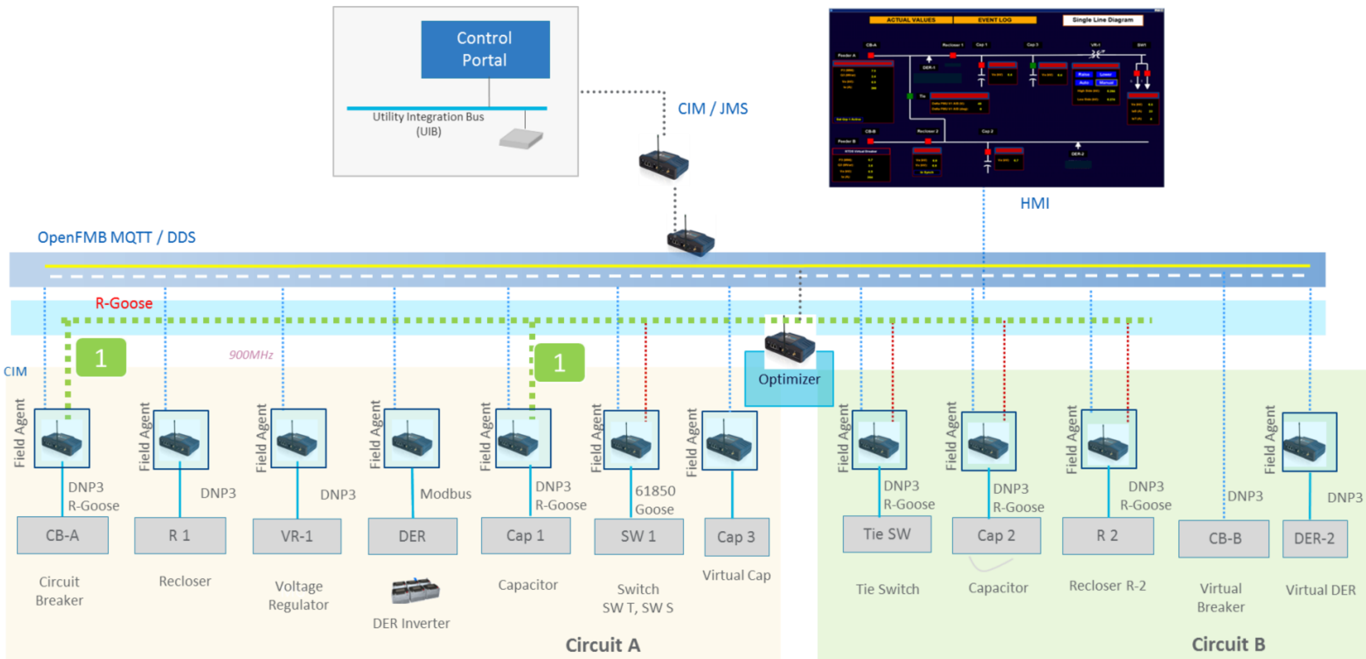
- Create a 2-line power system (Line A and Line B) with communicable devices on different networks on each line. Measure the Vars at the breaker end of Feeder A (CB-A).
- When the Vars exceed a set-point, send a R-GOOSE message from CB-A to Cap 1 to cut-in the capacitor at that location.
- Close Capacitor Cap 1

4.2 Test Case Diagram - UC 2a Var Control

Logical and IO Diagram



4.3 Test Case Diagram - UC 2a Var Control



Data Flow	*Data Flow Summary*	*Protocol*
1.	CB-A → CAP 1	CB-A → R-GOOSE → CAP 1

4.4 Test Case Pre-Conditions – UC 2a Var Control

Pre-Conditions	*Description*
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	OpenFMB pre-configured
3.	Multiple field agents connected and communicating via OpenFMB
4.	Optimizer Pre-configured
5.	Control Portal Pre-configured
6.	RTDS is Active
7.	Network Model with Switchable Devices (2 Circuits)
8.	Tie Switch is Open
9.	Cap 1 is Open
10.	Cap 2 is Open
11.	R-1 is Closed
12.	VR-1 is Auto Mode
13.	SW-1 is Closed (2 positions)
14.	CB-A is Closed
15.	CB-B is Closed

4.5 Test Case Test Steps – UC 2a Var Control

Steps	***Description***	***Acceptance Criteria***	***Pass / Fail***
#	*Step Description*	*Describe Acceptance Criteria*	*Pass (P) / Fail (F)*
1.	Start Control Portal	Check the Control Portal & logs to verify CP is running	P
2.	Start Field Agents / Optimizer	Check the log and verity Field Agents are up running. The measurement values shall be published and have values.	P Measurement values are displayed
3.	Measure the VARS at the breaker Feeder A (CB-A).	Measurement value VARS at Feeder A Breaker (CB-A)	2.1 MVAr
4.	Change VARS in the RTDS model to exceed a set-point	VARS exceed set-point	3.5 MVAr > threshold of 3.36 MVAr
5.	Send R-GOOSE message from CB-A to CAP 1 to Close capacitor CAP 1	R-Goose Message (Close) sent CB-A --> CAP 1, record the new Var values	Pass
6.	Sent R-GOOSE message received by CAP 1 capacitor	R-Goose Message received by capacitor (CAP 1) Status change = Close	Pass
7.	Measure the VARS at the breaker Feeder A (CB-A).	Measure VARS at Breaker (Feeder A) (OpenFMB) - view the new Var values	3.5

4.6 Test Case Results– UC 2a Var Control

Operational:

In this use case, the VAR loading on Line A is increased to a value above the pick-up value set in the Feeder A relay. Upon detection of the Over VAR condition, a CLOSE message is sent to Capacitor 1 via R-GOOSE. The oscillography below in figure 2a-1 shows increase in VARS, the Closing of the Capacitor 2 breaker in 6 cycles and the subsequent drop in VARS when the capacitor cuts in. The 6 cycle delay can be broken down into a 4 cycle delay on over-VAR detection, a 1.5 cycle communication time through the radios, a 4ms receipt delay, a 3ms output operation time, and some RTDS contact recognition time.

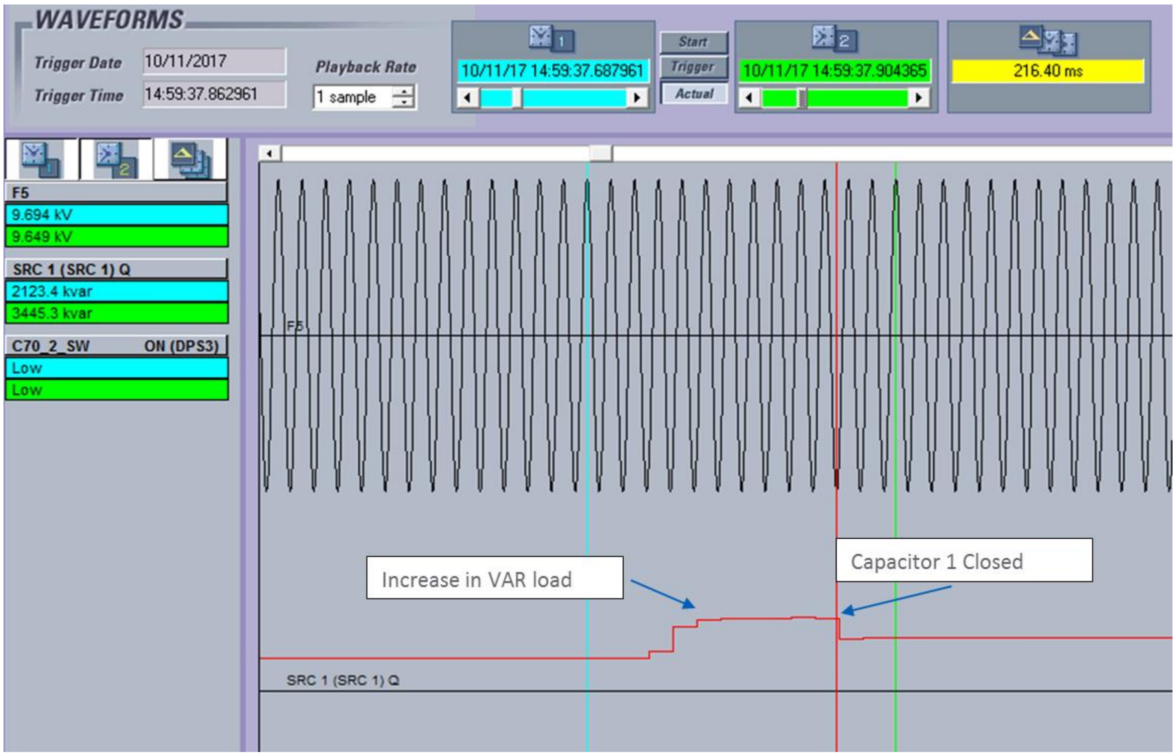


Figure 2a-1

Over-Var Line Condition with Capacitor Closing

Communication Observations:

During the implementation of this project, as the team learned about R-GOOSE, it was considered to play a roll in the "other" category of the OpenFMB Framework. R-GOOSE is a Pub-Sub protocol and is part of the IEC 61850 suite of profiles. R-GOOSE is similar to the non-guaranteed version of DDS in that it repeats a message continuously – independent of a Transport Layer time-out function. It is to be noted that this mode of communication optimizes performance for lost packets as there is no time delay in waiting for a lost packet "time-out". Also, similar to one of the modes of operation of DDS, R-GOOSE continues to send the message – the one difference being that DDS stops transmission when a "Packet Received" confirmation is received. Alternatively, R-GOOSE continues to send the last message state as a keep-alive. The Subscribers (all of them) can issue an alarm on loss of the keep-alive message after a message-specified period of time. Additionally, R-GOOSE optimizes the packet payload through a binary mapping of data in the packet through the use of the Abstract Syntax Notation presentation protocol. Communication of the R-GOOSE message was through a combination of a 100Mb Substation switch and a 500kb radio. It is to be noted that there was a periodic flow of Multicast data on the overall network as all R-GOOSE publishers sent keep-alive messages every 10 seconds. It is to be noted, however, that the R-GOOSE message was only 300 bytes long on the average whereas, an OpenFMB message (as presently mapped) was 5,000 bytes long.

OpenFMB Gaps:

It is once again of interest to note the concise nature of the R-GOOSE message and the need for OpenFMB to adopt this concise communication profile if it is to be a contender for communication at the edge.

Recommendations:

In the capacitor control use case, it is clear that the Pub-Sub model is key so implementation of such profiles is optimal. In as much as R-GOOSE meets the Pub-Sub profile, it can be considered in the "Other" category of the OpenFMB reference architecture. Implementations of MQTT and DDS should consider using the Binary mapping payload data and using an out-of-band payload identification mechanism.

5 Test Case 2b Man-in-the-Middle Augmented Voltage/Var Control

5.1 Test Case Description – UC 2b Man-in-the-Middle Augmented Voltage/Var Control

UC 2b Man-in-the-Middle Augmented Voltage/Var Control

Objective:

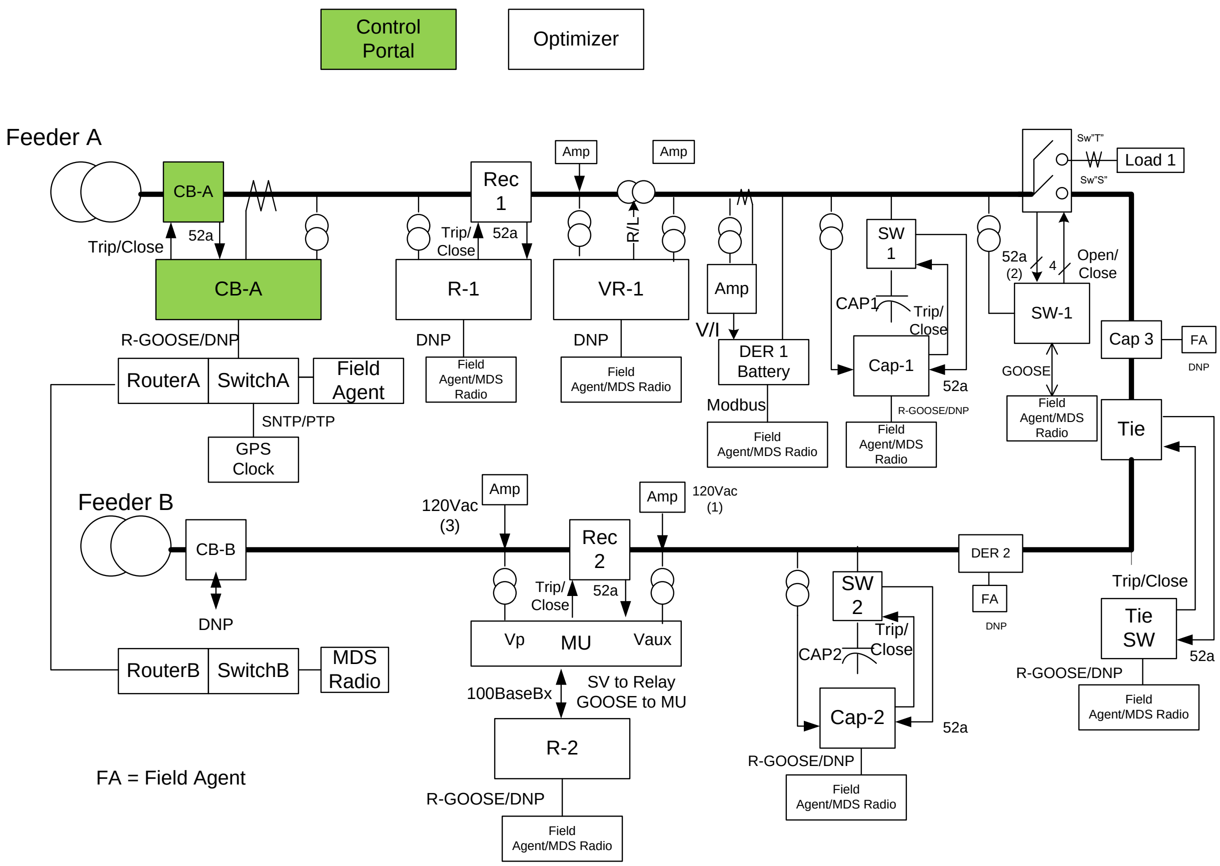
- Demonstrate manual control and operation using OpenFMB

Description:

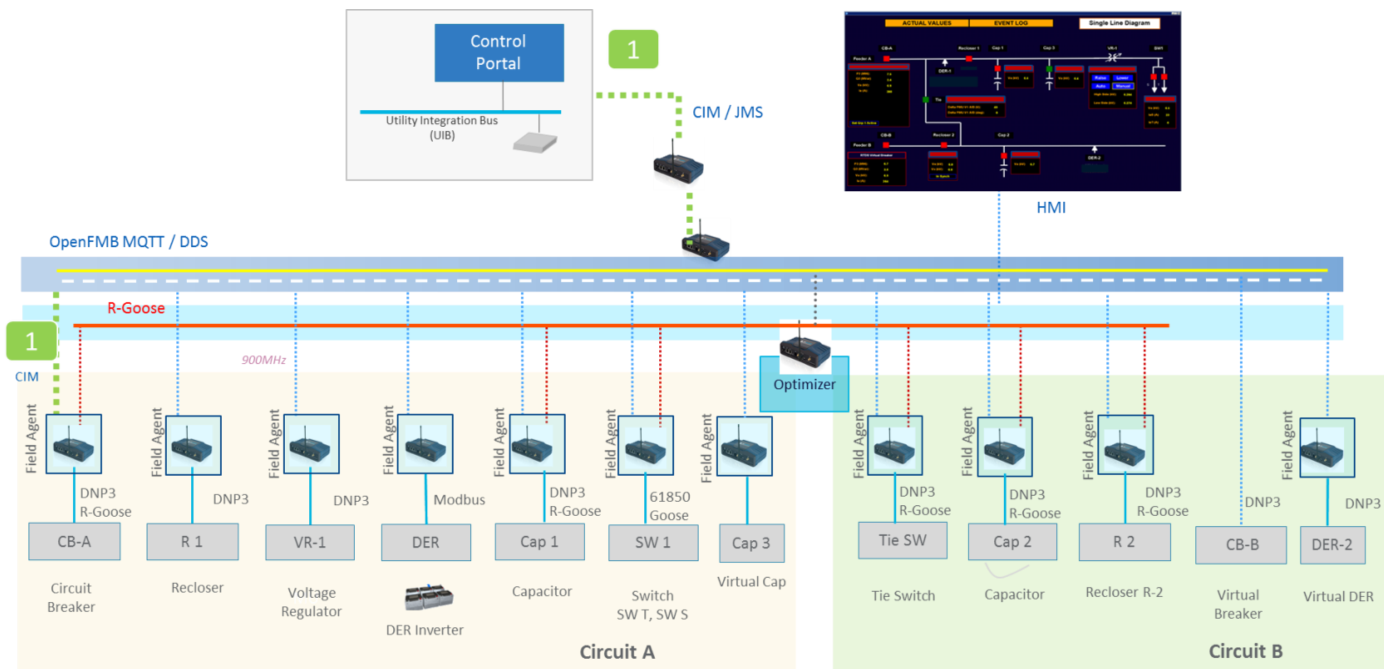
- If, after closing Capacitor 1, the var level is still above the setting threshold in the CB-A, a OpenFMB alarm of “over VAR” will be issued by the CB-A relay.
- This alarm is to be received by the Control Portal and indicated.
- Pre-condition VR-1 is in manual mode.

5.2 Test Case Diagram – UC 2b Man-in-the-Middle Augmented Voltage/Var Control

Logical and IO Diagram



5.3 Test Case Diagram – UC 2b Man-in-the-Middle Augmented Voltage/Var Control



Data Flow	***Data Flow Summary***	***Protocol***
1.	CB-A → Field Agent →Control Portal (CP)	CB-A → DNP → OpenFMB(MQTT) → CP

5.4 Test Case Pre-Conditions – UC 2b Man-in-the-Middle Augmented Voltage/Var Control

Pre-Conditions	***Description***
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	OpenFMB pre-configured
3.	Multiple field agents connected and communicating via OpenFMB
4.	Optimizer Pre-configured
5.	Control Portal Pre-configured
6.	RTDS is Active
7.	Network Model with Switchable Devices (2 Circuits)
8.	Tie Switch is Open
9.	Cap 1 is Closed
10.	Cap 2 is Open
11.	R-1 is Closed
12.	VR-1 is Manual Mode (not a normal operating state)
13.	SW-1 is Closed (2 positions)
14.	CB-A is Closed
15.	CB-B is Closed

5.5 Test Case Test Steps – UC 2b Man-in-the-Middle Augmented Voltage/Var Control

Steps	***Description***	***Acceptance Criteria***	***Pass / Fail***
#	*Step Description*	*Describe Acceptance Criteria*	*Pass (P) / Fail (F)*
1.	Measure the VARS at the breaker Feeder A (CB-A).	Measurement value = VARS at Breaker (CB-A) still above normal	2.1MVAR
2.	Change VARS in the RTDS model to exceed a set-point if needed	VARS exceed set-point	3.4MVAR
3.	CB-A sends an alarm of “over VAR”	F-60-1 sent "over VAR" alarm (OpenFMB)	P
4.	Control Portal receives Alarm	Control Portal receives "over VAR" alarm (OpenFMB)	P
5.	Operator places VR-1 in Auto mode	Observe VR-1 in Auto mode	P

5.6 Test Case Results – UC 2b Man-in-the-Middle Augmented Voltage/Var Control

Operational:

As the VAR loading on the line was increased, as expected, the Over Var alarm from the feeder was observed on the control portal. From the Control Portal, the test engineer was able to manually CLOSE the Capacitor 1 breaker and manually add VAR support to the line.

Communication Observations:

The control command originated on the 100MHz network – which then transitioned to the 500KHz bandwidth of the radio network. Execution of the command was in the 1 to 3 second range – again, adequate for a HMI response time.

OpenFMB Gaps:

No gaps identified.

Recommendations:

The recommendations for this use car pertain only to the Control Portal where, again, better descriptions of the data items is needed as is a mechanism to pop-up alarms on the screen.

6 Test Case 2c – Peer-to-Peer Voltage/Var Control

6.1 Test Case Description – UC 2c Peer-to-Peer Voltage/Var Control

UC 2c Peer-to-Peer Voltage/Var Control

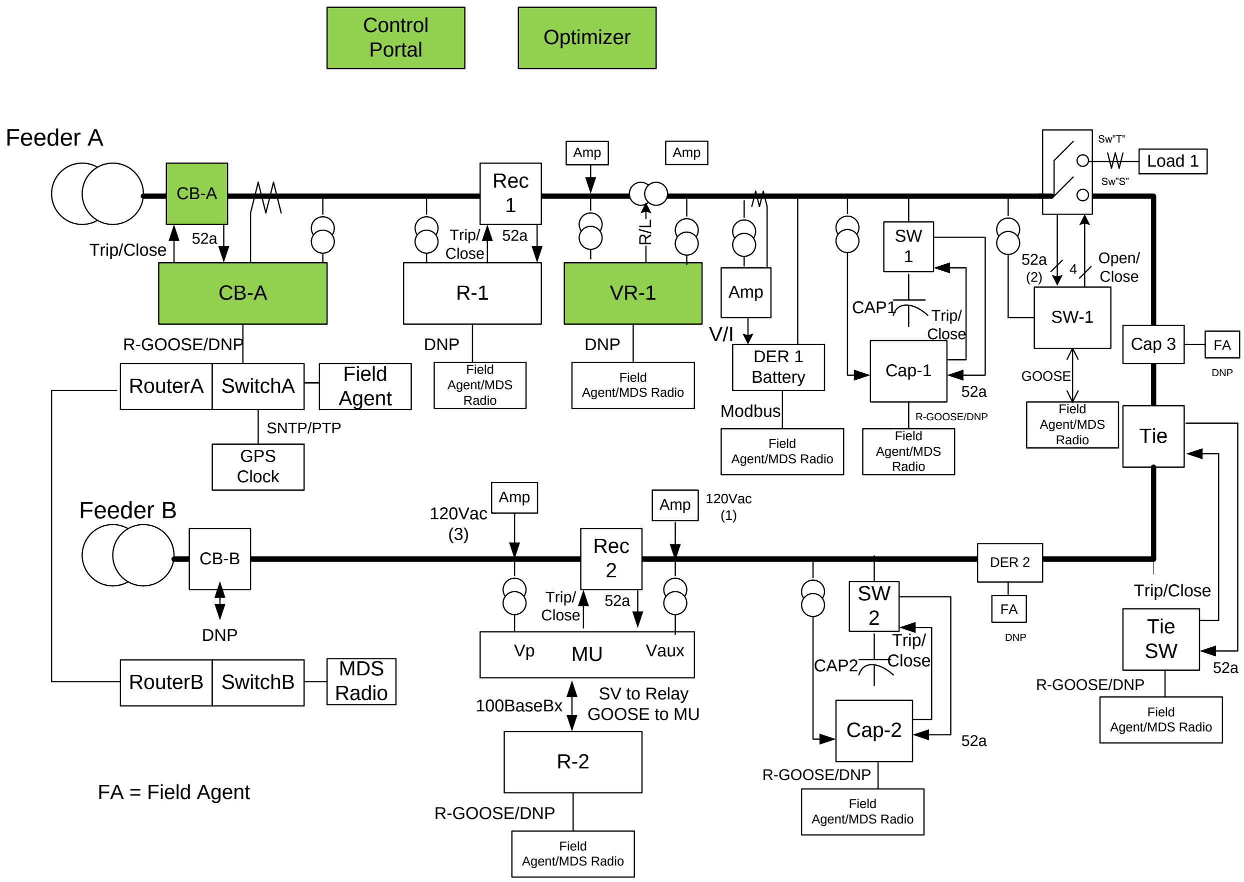
Objective:

- Demonstrate automated control or operation using OpenFMB

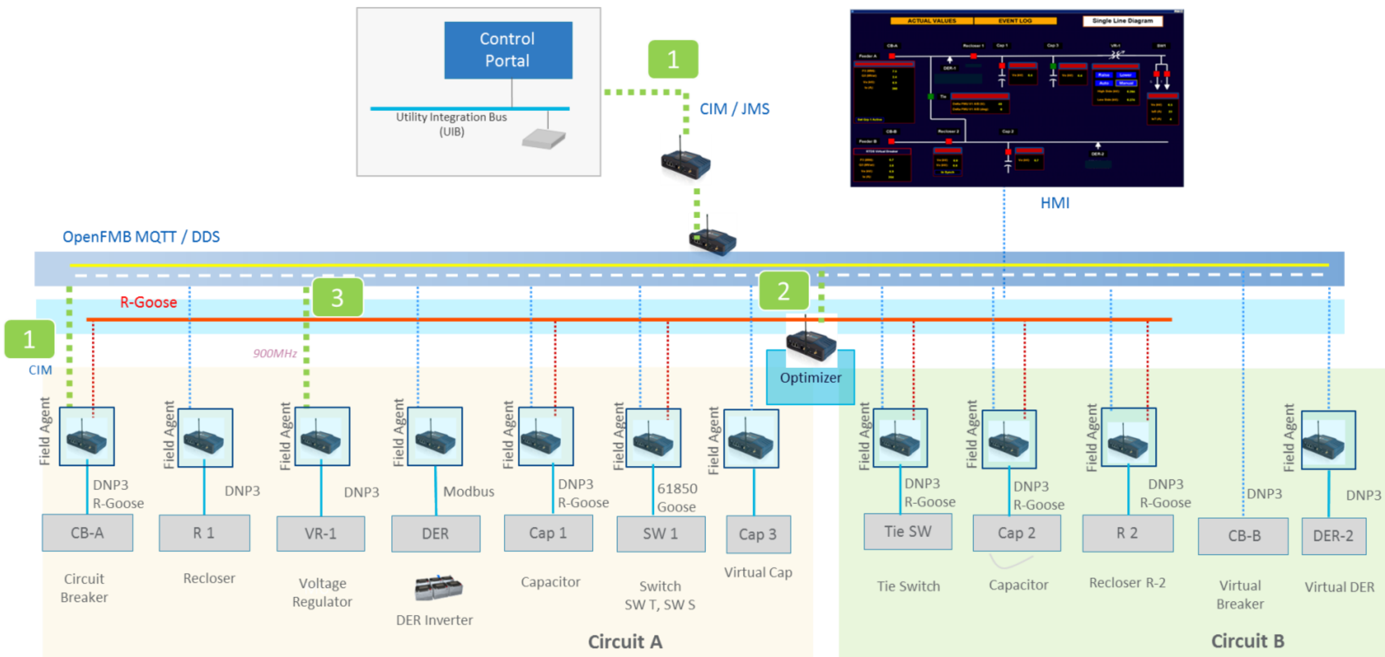
Description:

- If, after closing Capacitor 1, the var level is still above the setting threshold in the CB-A, an alarm of “over VAR” will be issued by the CB-A.
- This alarm is to be received by the Optimizer and the Optimizer then places VR-1 Voltage Regulator in auto mode via an OpenFMB command.
- Pre-Condition VR-1 manual mode
- Pre-Condition Cap 1 is closed
- RTDS raises VAR loading prior to start of test

6.2 Test Case Diagram – UC 2c Peer-to-Peer Voltage/Var Control



6.3 Test Case Diagram – UC 2c Peer-to-Peer Voltage/Var Control



Data Flow	*Data Flow Summary*	*Protocol*
1.	CB-A → Field Agent →Control Portal (CP)	CB-A → DNP → OpenFMB(MQTT) → CP
2.	CB-A → Field Agent →Optimizer	CB-A → DNP “over VAR “→ Field Agent (CIM) → OpenFMB(MQTT) → “over VAR” alarm Optimizer
3.	Optimizer → CIM → OpenFMB(MQTT) → VR-1	Optimizer → CIM → OpenFMB(MQTT) → Field Agent (CIM) → DNP → VR-1 (Auto Mode)

6.4 Test Case Pre-Conditions – UC 2c Peer-to-Peer Voltage/Var Control

Pre-Conditions	***Description***
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	OpenFMB pre-configured
3.	Multiple field agents connected and communicating via OpenFMB
4.	Optimizer Pre-configured
5.	Control Portal Pre-configured
6.	RTDS is Active
7.	Network Model with Switchable Devices (2 Circuits)
8.	Tie Switch is Open
9.	Cap 1 is Closed
10.	Cap 2 is Open
11.	R-1 is Closed
12.	VR-1 is manual Mode
13.	SW-1 is Closed (2 positions)
14.	Control Portal displays measurement values
15.	CB-A is Closed
16.	CB-B is Closed
17.	RTDS lowers the VAR loading below threshold

6.5 Test Case Test Steps – UC 2c Peer-to-Peer Voltage/Var Control

Steps	*Description*	*Acceptance Criteria*	*Pass / Fail*
#	*Step Description*	*Describe Acceptance Criteria*	*Pass (P) / Fail (F)*
1.	Measure the VARS at the breaker Feeder A (CB-A).	Measurement value = VARS at Breaker (CB-A) still above normal	0.7 MVAr
2.	Change VARS to exceed a set-point	VARS exceed set-point	90% change in Load Q (i.e above 3.4 MVAr).
3.	CB-A sends an alarm of "over VAR"	F-60-1 sends "over VAR" alarm	Pass
4.	Control Portal & Optimizer receives Alarm	Control Portal & Optimizer receives "over VAR" alarm	Pass
5.	Optimizer sends command to VR-1 switch to manual mode	VR-1 switches to manual mode	Pass
6.	VR-1 regulates to a previously issued set-point in manual mode	VR-1 placed in manual mode	Pass
7.	VR-1 Regulator Control through Control Portal	Parking Lot Enhancement	Parking Lot
8.	Measure the VARS at the breaker Feeder A (CB-A).	Measurement value = VARS at Breaker (CB-A) still above normal	3.4 MVAr

6.6 Test Case Results – UC 2c Peer-to-Peer Voltage/Var Control

Operational:

In this use case, the continued Over VAV condition exists on the feeder and there is a need to adjust VAR flow through MANUAL control of the Voltage Regulator. As such, a “RULE” was created in the optimizer to set the Voltage Regulator to MANUAL mode. NOTE: this was an arbitrary decision as the rule could have as easily been switched from Manual to Auto mode.

Communication Observations:

Communication in this case was OpenFMB from the Substation relay through the 100MB Ethernet switch to the Control Portal and then from the Substation relay through the 500kB radio network to the Voltage Regulator. Communication performance in each stage was on the order of 2 seconds per stage.

OpenFMB Gaps:

Not part of OpenFMB today but configuration of the “RULES” engine and observation of its performance needs to be addressed. The RULES were implemented using a LINUX rules engine – DROOLS – into which there was no visibility from the Control Portal. Additionally, the logging of any RULE execution needs to be addressed.

Recommendations:

The incorporation of RULE and general logic development, monitoring, and logging should be considered in any OpenFMB profile. Ideally, all profiles would use the same LOGIC development profile and would use an internationally standardized logic language.

7 Test Case 2d – Voltage Override

7.1 Test Case Description – UC 2d Voltage Override

UC 2d Voltage Override

Objective:

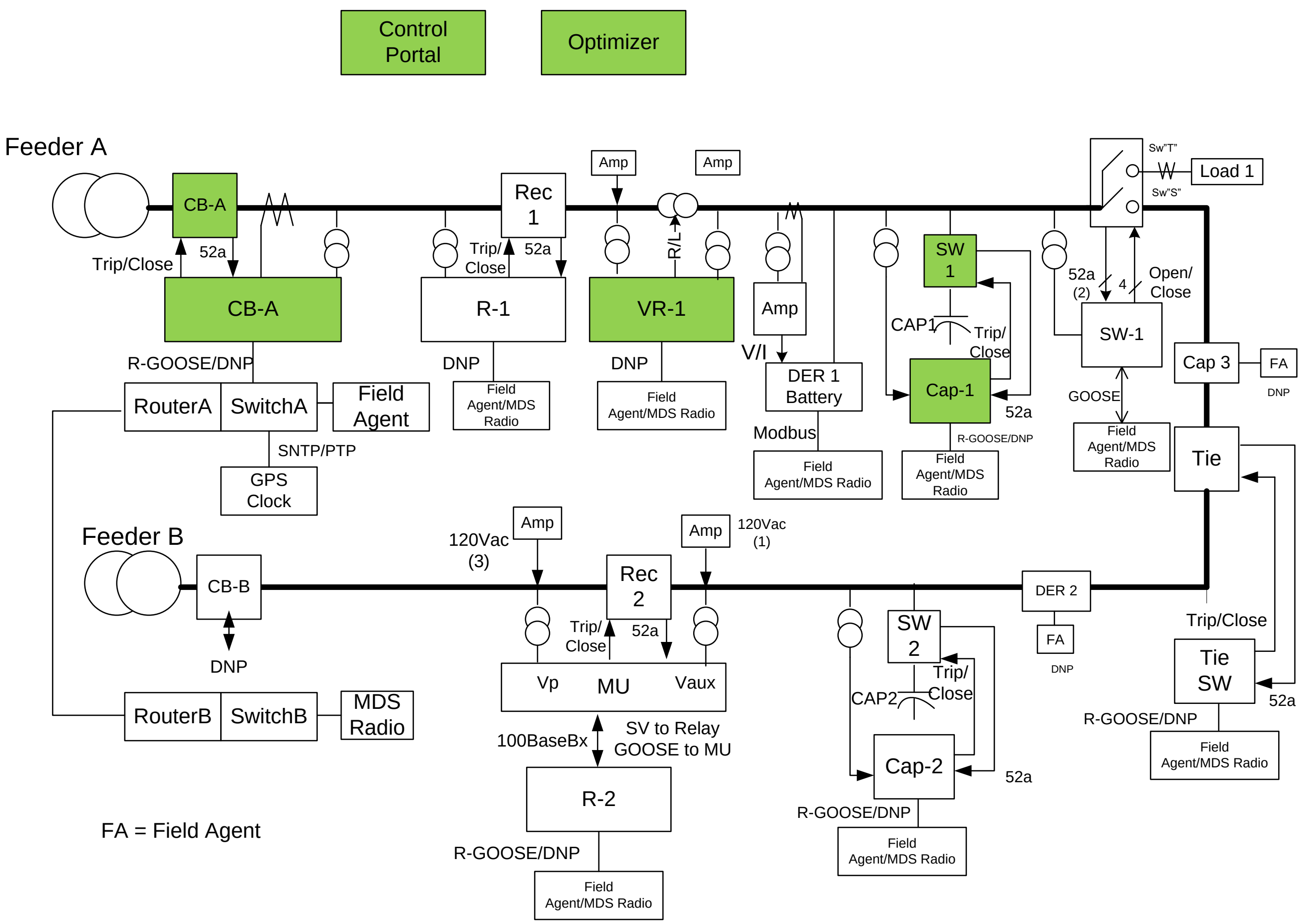
- Demonstrate the communication of the rejection of manual control and subsequent automatic response based on prevailing local condition using OpenFMB.

Description:

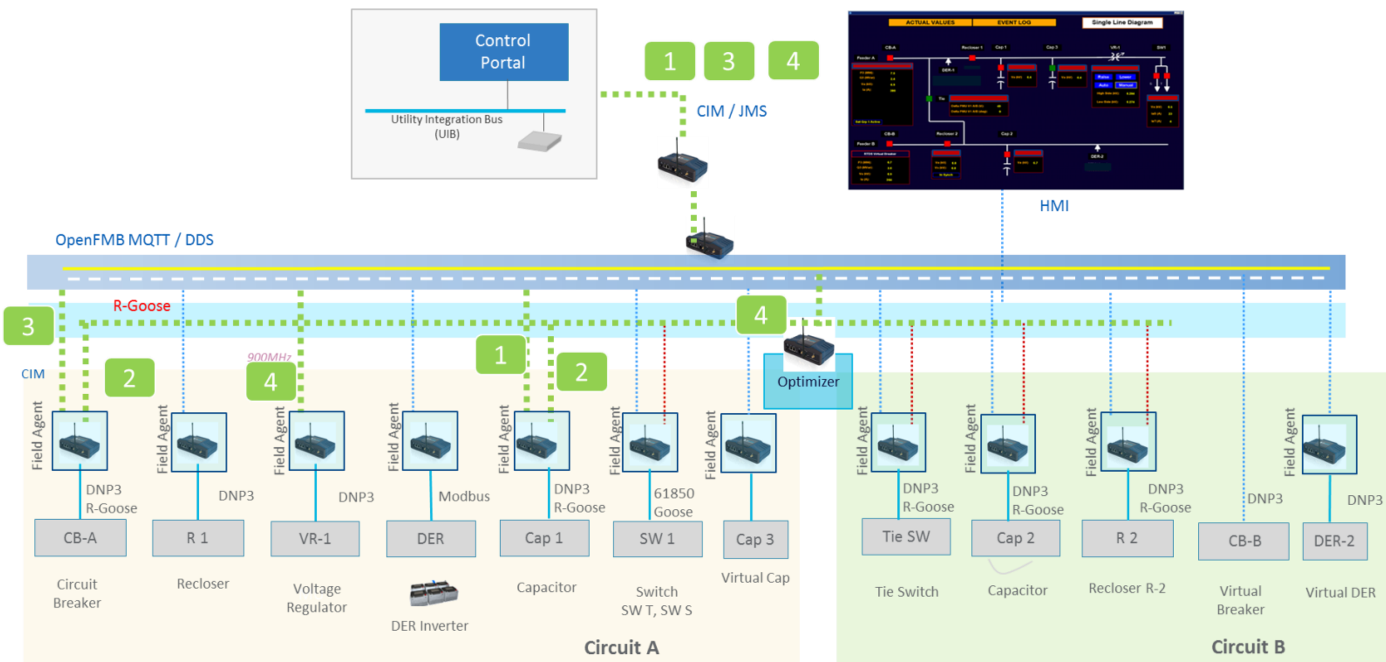
- Control Portal sends a close command to CAP 1
- If the voltage on CAP 1 is too high, CAP 1 refuse the CLOSE control and send a message to the CB-A indicating refusal of the Cap 1 devices to execute the requested close action.
- An OpenFMB message is issued indicating such from CB-A and is to be displayed on the Control Portal.
- Detection of Over-Voltage shall be transmitted to the Optimizer which will then enable the Voltage Regulator.
- Pre-condition: Voltage Regulator (VR-1) Manual Mode & high voltage (circuit A) through RTDS
- Post-condition: Voltage Regulator (VR-1) turned to Automatic Mode

7.2 Test Case Diagram – UC 2d Voltage Override

Logical and IO Diagram



7.3 Test Case Diagram – UC 2d Voltage Override



Data Flow	*Data Flow Summary*	*Protocol*
1.	Control Portal (CP) → OpenFMB(MQTT) → Field Agent → CAP 1	CP → CIM/JMS → OpenFMB(MQTT) → Field Agent (CIM) → DNP → CAP 1 (Close)
2.	CAP 1 → CB-A	CAP 1 → R-GOOSE → CB-A
3.	CB-A → Refuse Close → Control Portal (CP)	CB-A → DNP → Field Agent (CIM) → OpenFMB(MQTT) → CIM/JMS → CP
4.	Control Portal (CP) → Optimizer → VR-1	CP → CIM/JMS → OpenFMB(MQTT) → Optimizer → OpenFMB(MQTT) → Field Agent (CIM) → DNP → VR-1 (Auto Mode)

7.4 Test Case Pre-Conditions – UC 2d Voltage Override

Pre-Conditions	***Description***
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	OpenFMB pre-configured
3.	Multiple field agents connected and communicating via OpenFMB
4.	Optimizer Pre-configured
5.	Control Portal Pre-configured
6.	RTDS is Active
7.	Network Model with Switchable Devices (2 Circuits)
8.	Tie Switch is Open
9.	Cap 1 is Open
10.	Cap 2 is Open
11.	R-1 is Closed
12.	VR-1 is Manual Mode
13.	SW-1 is Closed (2 positions)
14.	Control Portal displays measurement values
15.	CB-A is Closed
16.	CB-B is Closed
17.	RTDS voltage needs to raise to 1.6 PU

7.5 Test Case Test Steps – UC 2d Voltage Override

Steps	***Description***	***Acceptance Criteria***	***Pass / Fail***
#	*Step Description*	*Describe Acceptance Criteria*	*Pass (P) / Fail (F)*
1.	Monitor Voltage on Cap 1	CAP 1 measurement value (Voltage)	7.1kV
2.	Monitor Voltage on CAP 1	CAP 1 measurement value (Voltage)	6.8kV
3.	RTDS Simulate increase in voltage (High Voltage) on Cap 1 CAP 1	CAP 1 measurement value (High Voltage)	Voltage increased to the threshold of 7.416 on the Cap CAP 1
4.	Control Portal sends Close command CAP 1	CAP 1 receive command CAP 1 = closed	Closed
5.	Cap 1 refuse the CLOSE control	CAP 1 CLOSE control refused	Pass
6.	Cap 1 sends message to CB-A indicating refusal	CB-A monitors CAP 1 close control refusal	Pass
7.	CB-A creates message "Over-Voltage" sends to Optimizer	Optimizer receives "Over-Voltage" message	Received
8.	Optimizer sends message VR-1 to change to auto mode	Optimizer sends VR-1 to change to auto mode	Pass
9.	Voltage Regulator VR-1 receives command	VR-1 receives auto mode command	Auto
10.	Voltage Regulator VR-1 regulates voltage on the low side	VR-1 lowers the voltage on the low side	Voltage reduced to 7.47

7.6 Test Case Results – UC 2d Voltage Override

Operational:

In this use case, the voltage on Capacitor 1 is too high. When a manual close is attempted, the Capacitor Controller refuses the request and notifies the Feeder Breaker relay of such. In response to this situation, the Feeder Breaker relay issues an OpenFMB command to place the Voltage Regulator into Auto mode.

Figures 2d-1 and 2d-2 below shows this transaction in detail. In figure 2d-1, one can see the increase in voltage and decrease in current. Figure 2d-2 shows the VAR response of the feeder (drop in VARs as the Voltage increases) with the response of placing the regulator into AUTO mode. Note that there was a 10 second delay timer in the voltage regulator before the first step is taken. The stepping of the regulator can be clearly seen in figure 2d-2.

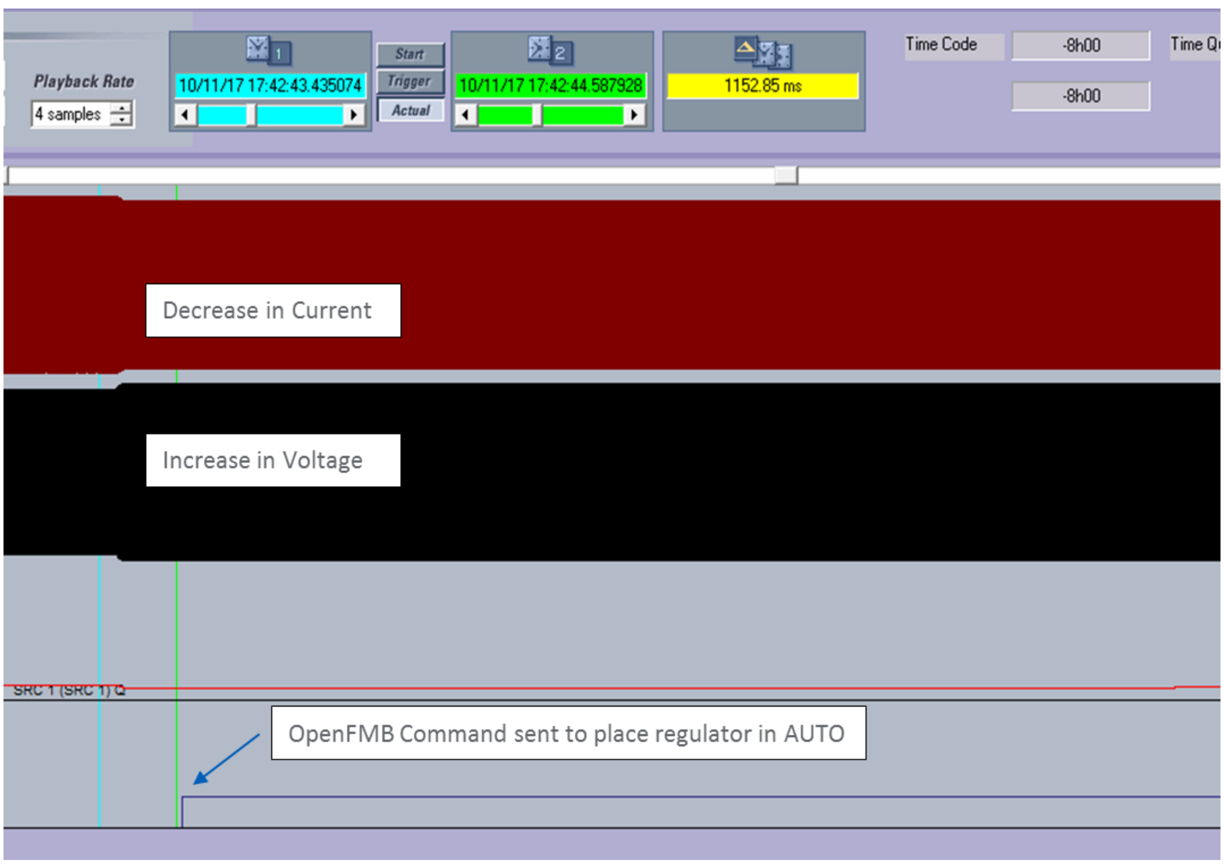


Figure 2d-1

Feeder A Voltage Increase

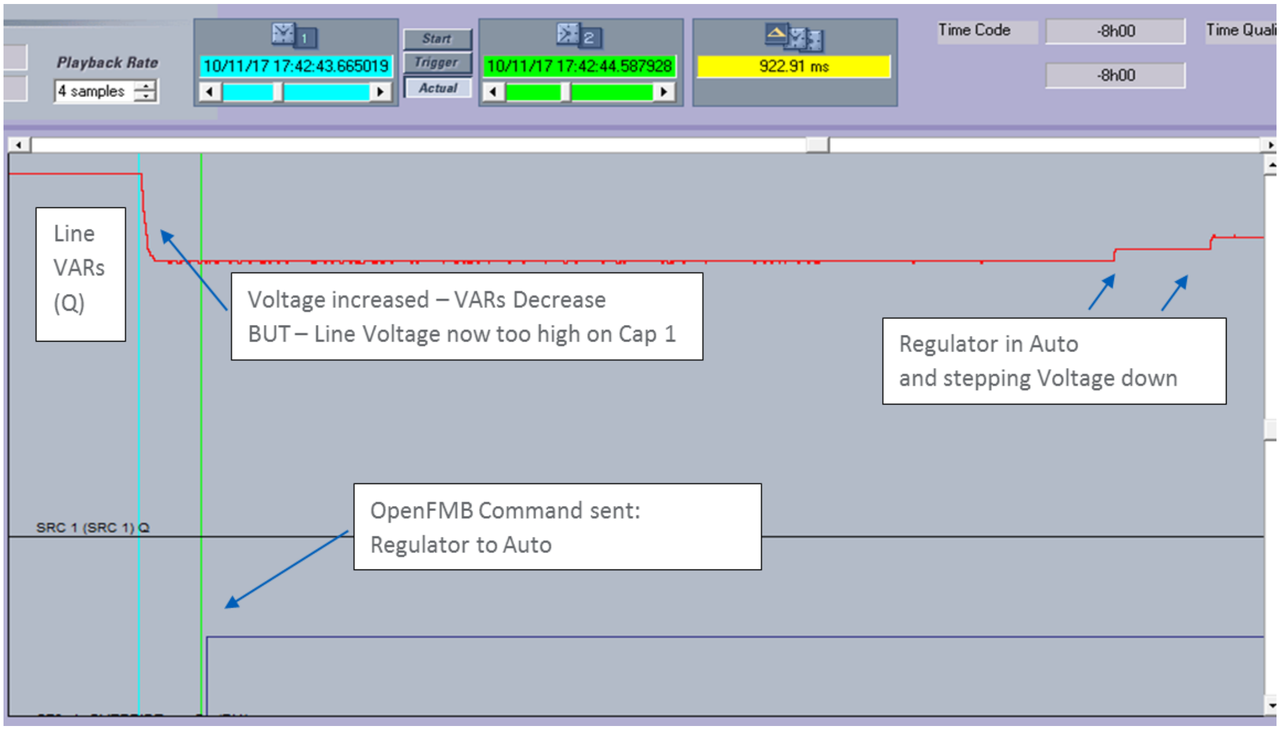


Figure 2d-2

Expanded VAR Response with Regulator Action

Communication Observations:

Device to device communication for this case used messaging from the Feeder A relay to the Optimizer (where the RULE engine resided) which then issued a message to the Voltage Regulator. The message transport to the Optimizer was the Message Queue Telemetry Transport protocol (MQTT). As captured by WireShark, the anatomy of this message can be seen in figure 2d-3. In this snippet from WireShark, one can see the protocol listed and the face that TCP combined packets of 1448, 1448, and 546 bytes for a total message length of 3442 bytes. The major part of the payload was the XML description of the data being transmitted over the wire.

```
▷ Frame 6: 612 bytes on wire (4896 bits), 612 bytes captured (4896 bits) on interface 0
▷ Ethernet II, Src: TexasIns_ae:ce:7e (04:a3:16:ae:ce:7e), Dst: Vmware_9b:6e:c7 (00:0c:29:9b:6e:c7)
▷ Internet Protocol Version 4, Src: 172.16.42.220, Dst: 172.16.42.225
▷ Transmission Control Protocol, Src Port: 45624, Dst Port: 1883, Seq: 2897, Ack: 1, Len: 546
▷ [3 Reassembled TCP Segments (3442 bytes): #4(1448), #5(1448), #6(546)]
◢ MQ Telemetry Transport Protocol, Publish Message
  ◢ Header Flags: 0x30 (Publish Message)
      0011 .... = Message Type: Publish Message (3)
      .... 0... = DUP Flag: Not set
      .... .00. = QoS Level: At most once delivery (Fire and Forget) (0)
      .... ...0 = Retain: Not set
    Msg Len: 3439
    Topic Length: 38
    Topic: MQTTMeasurementValueUpdateEventService
    Message [truncated]: <?xml version="1.0" encoding="UTF-8" standalone="yes"?><ns2:MeasurementValueUpdateEvent xmlns:ns2=
```

Figure 2d-3

MQTT Message Anatomy

OpenFMB Gaps:

Again, it is to be noted that the transmission of XML over the wire is verbose and needs to be re-structured into an itemized and structured dataset. Alto to be noted is that the Broker in MQTT add not only a time delay in the messaging but also adds a potential failure mode.

Recommendations:

A simple analysis of the MQTT architecture vs. the R-GOOSE architecture can be made. Using an MTBF of 30 years for the elements in an R-GOOSE and MQTT system, the MQTT architecture required 3 devices (Publisher, Subscriber, and Broker) for an overall MTBF of 10 years. The R-GOOSE system (ignoring the Ethernet switch in both cases) only has 2 elements – a Publisher and a Subscriber. The overall MTBF for this 2-element system is 15 years. The follow-up discussion must then compare the use of UDP vs. TCP. TCP will continue to re-request the transmission of a dataset for “minutes” whereas R-GOOSE does no re-request, however, R-GOOSE will re-transmit up to 4 times in a 16ms period – effectively imitating the TCP functionality. Additionally, while in “keep alive” mode, the R-GOOSE will continue to re-transmit the last changes message state – until a new change occurs. It is to be noted that although there is no “direct” acknowledgement of the receipt of an R-GOOSE message, application level messaging can be created to acknowledge the receipt of a message from any number of subscribers to the publisher.

8 Test Case 3a – Inter-network Var Control

8.1 Test Case Description – UC 3a Inter-network Var Control

UC 3a Inter-network Var Control

Objective:

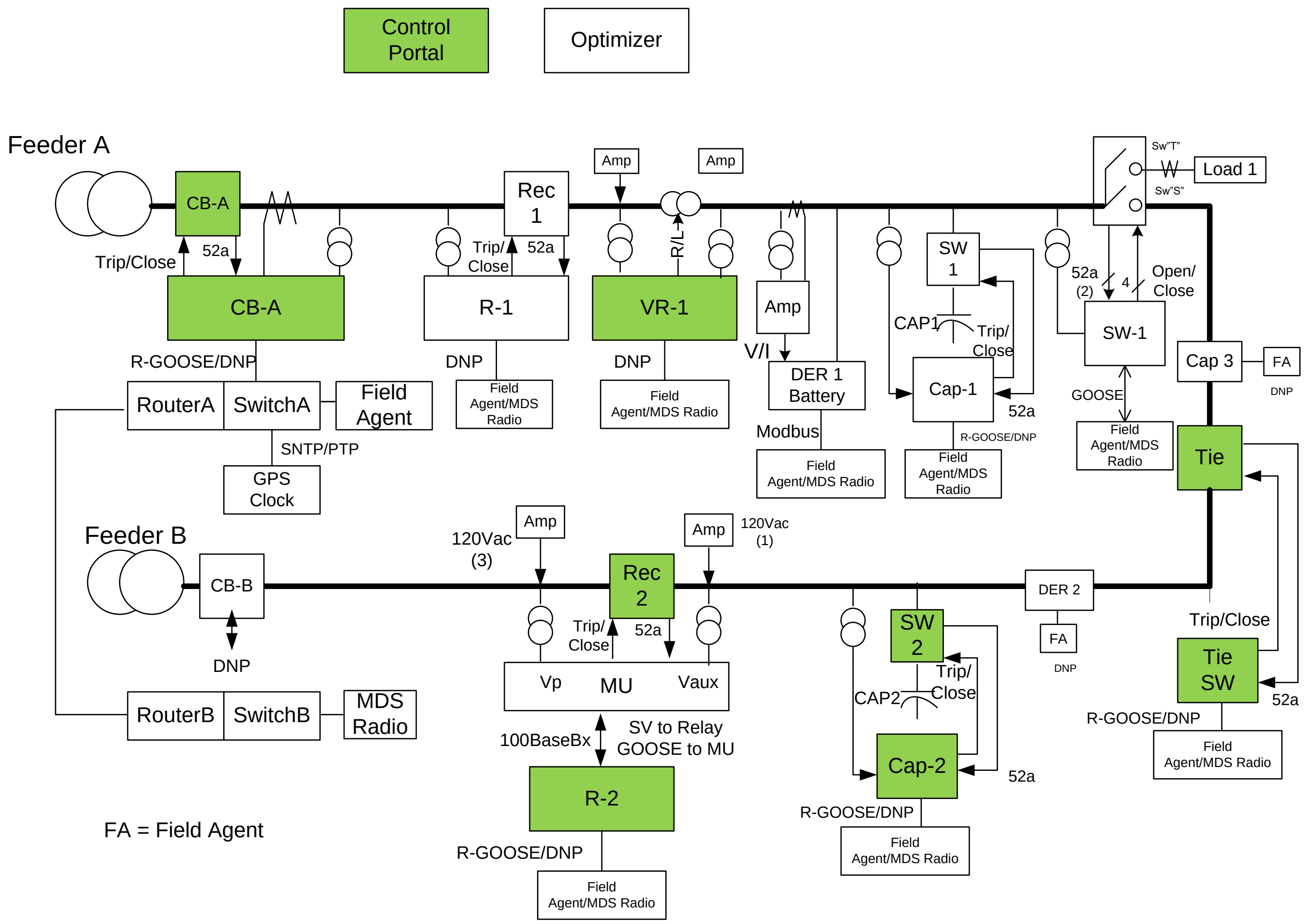
- Demonstrate Inter-network communication capability of OpenFMB

Description:

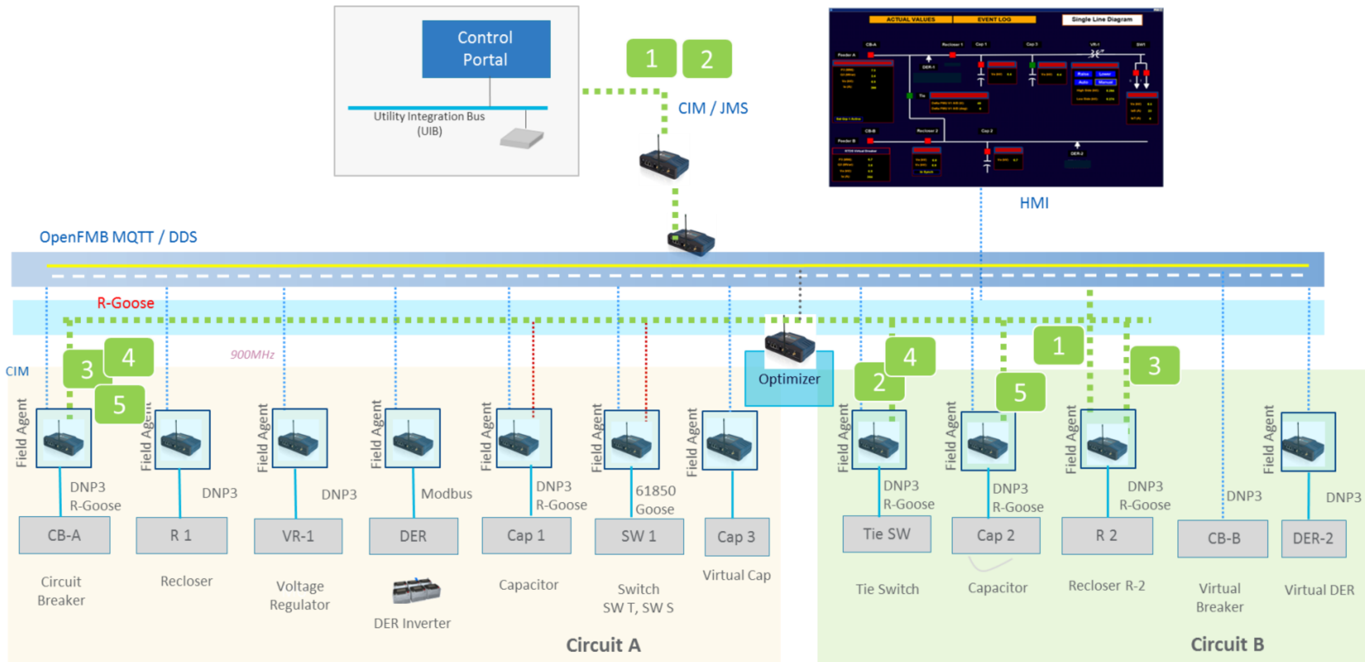
- Building on Test Case 2a, b, c, d.
- Using OpenFMB issues command from the Control Portal to open Recloser 2 R-2 and then close the TIE switch (Tie SW).
- The status of Recloser 2 and Tie Breaker are monitored by the R-2 and Tie SW relays respectively.
- This information is then sent – internetwork via R-GOOSE to CB-A.
- Var load on the feeder is then increased above the setting threshold.
- The CB-A then makes a determination to close Capacitor 2 for additional var support.
- Pre-condition: Capacitor Bank 1 is CLOSED and the Voltage Regulator (VR-1) is manual mode.
- Pre-condition: CB-B is open

8.2 Test Case Diagram – UC 3a Inter-network Var Control

Logical and IO Diagram



8.3 Test Case Diagram – UC 3a Inter-network Var Control



Data Flow	*Data Flow Summary*	*Protocol*
1.	Control Portal (CP) → OpenFMB(MQTT) → Field Agent → R-2	CP → CIM/JMS → OpenFMB(MQTT) → Field Agent (CIM) → DNP → R-2 (Open)
2.	Control Portal (CP) → OpenFMB(MQTT) → Field Agent → c	CP → CIM/JMS → OpenFMB(MQTT) → Field Agent (CIM) → DNP → Tie SW (Close)
3.	R-2 → CB-A	R-2 → R-GOOSE → CB-A (Status Change)
4.	Tie SW → CB-A	Tie SW → R-GOOSE → CB-A (Status Change)
5.	CB-A → CAP 2	CB-A → R-GOOSE → CAP 2 (Close)

8.4 Test Case Pre-Conditions – UC 3a Inter-network Var Control

Pre-Conditions	***Description***
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	OpenFMB pre-configured
3.	Multiple field agents connected and communicating via OpenFMB
4.	Optimizer Pre-configured
5.	Control Portal Pre-configured
6.	Network Model with Switchable Devices (2 Circuits)
7.	Tie Switch is Open
8.	Cap 1 is Close
9.	Cap 2 is Open
10.	R-1 is Closed
11.	VR-1 is manual
12.	SW-1 is Closed (all 2 positions)
13.	Control Portal displays measurement values
14.	R-2 is Closed
15.	CB-B is Open

8.5 Test Case Test Steps – UC 3a Inter-network Var Control

Steps	***Description***	***Acceptance Criteria***	***Pass / Fail***
#	*Step Description*	*Describe Acceptance Criteria*	*Pass (P) / Fail (F)*
1.	Start Control Portal	Check the Control Portal & logs to verify the OpenFMB is up running	Pass
2.	Start Field Agents	Check the log and verity Field Agents are up running. The measurement value shall be published and have values.	P, Measurement values are displayed
3.	Control Portal - open Recloser 2 (R-2) Open Command	Recloser 2 open - status change R-2 = open	Pass
4.	Control Portal - close (TIE SW) Close Command	Tie SW Closed - status change Tie SW = close	Pass
5.	R-2 monitors device status R2 Open	R-2 Receives messages R-2 = open, Tie SW = close	Pass
6.	Tie SW monitors device status Tie SW Close	Tie SW Receives messages R-2 = open, Tie SW = close	Pass
7.	Var load on the feeder is increased above the setting threshold.	CB-A VAR load increased by simulation	3.2 MVAr to 6.3 MVAr to 5.8 MVAr
8.	CB-A Monitors network - determination to close Cap 2	CAP 2 close - Cap 2 = Close	Pass
9.	CB-A Closes Cap 2 (R-Goose)	CAP 2 close - Cap 2 = Close	Pass
10.	Control Portal Displays measurement values	CP displays measurement values	Pass

8.6 Test Case Results – UC 3a Inter-network Var Control

Operational:

In this use case, an OpenFMB command was issued from the Control Portal to open Recloser 2 and then close the TIE switch using MQTT. The var load on the feeder was then increased above the setting threshold requiring additional support from Capacitor 2.

Communication Observations:

The controls were carried via xml as mapped into a MQTT data frame. Periodically the command would fail however, all retries were successful. The reason for failure is theorized to be the traffic on the network. Specifically, on the 900 MHz network which was operating at 500bps.

OpenFMB Gaps:

The messages are large is size. A standardized binary mapping of the data items will be a requirement to review with future analysis.

Recommendations:

Increase the performance of the network by reducing packet size. Specifically, when considering operation over a radio network.

9 Test Case 3b – Peer-to-Peer Volt/Var Control

9.1 Test Case Description – UC 3b Peer-to-Peer Volt/Var Control

UC 3b Peer-to-Peer Volt/Var Control

Objective:

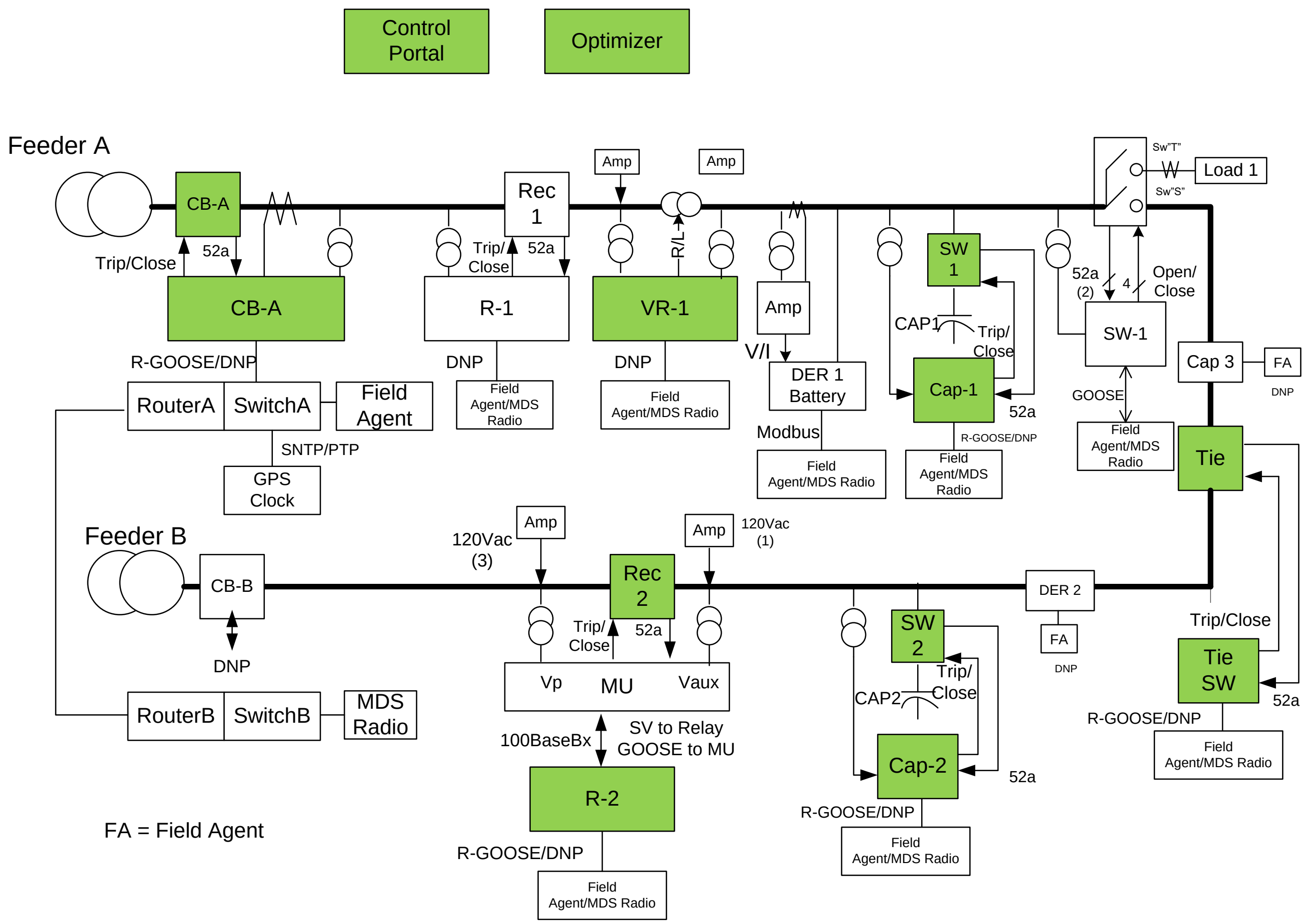
- Demonstrate Peer-to-Peer communication capability of OpenFMB to achieve progressive Var support.

Description:

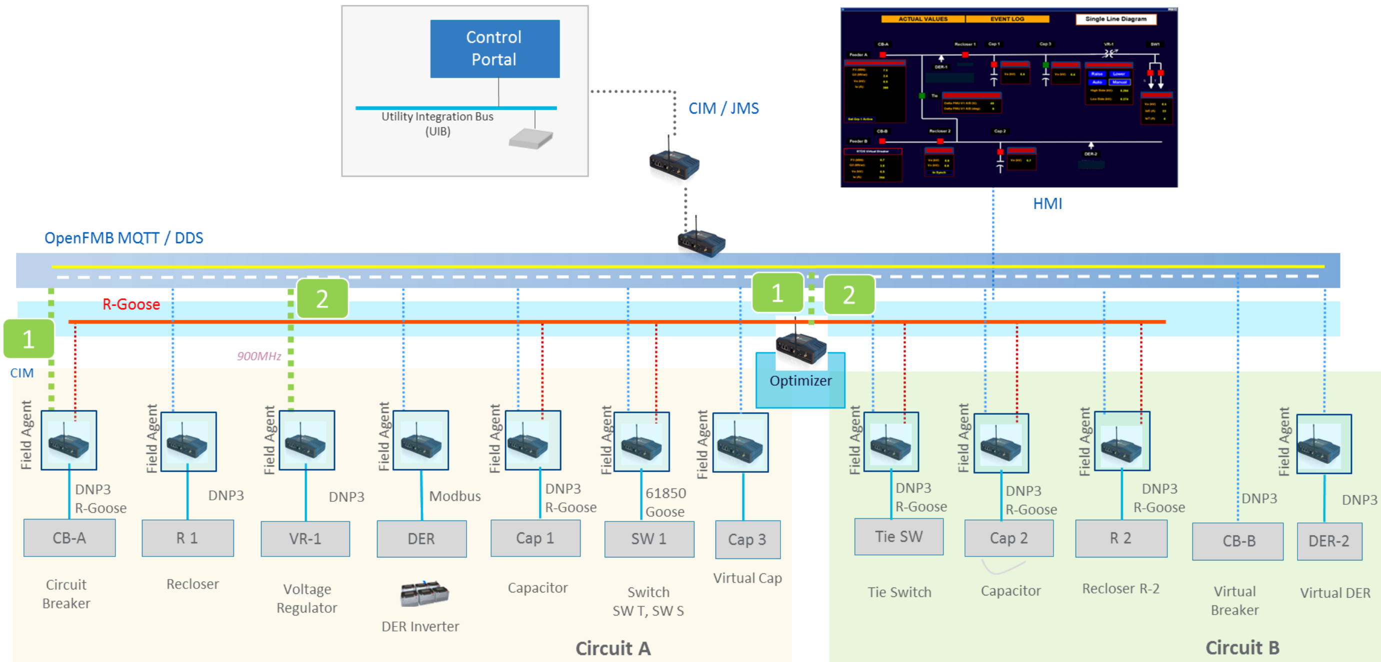
- Given that Capacitor 1 is closed AND the Tie SW is closed AND Capacitor Bank 2 is closed.
- The var load on the line is then further increased above the setting threshold.
- The CB-A then issues a signal (High Var) to the Optimizer that additional var support is needed.
- Upon receipt of a High Var message, the Optimizer will then switch the Voltage Regulator (VR-1) to manual mode.
- Pre-Condition: Voltage Regulator (VR-1) is in Auto mode

9.2 Test Case Diagram – UC 3b Peer-to-Peer Volt/Var Control

Logical and IO Diagram



9.3 Test Case Diagram – UC 3b Peer-to-Peer Volt/Var Control



Data Flow	*Data Flow Summary*	*Protocol*
1.	CB-A → Optimizer	CB-A → DNP → Field Agent (CIM) → OpenFMB(MQTT) → Optimizer
2.	Optimizer → VR-1	Optimizer → OpenFMB(MQTT) → Field Agent → DNP → VR-1 (Manual Mode)

9.4 Test Case Pre-Conditions – UC 3b Peer-to-Peer Volt/Var Control

Pre-Conditions	*Description*
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	OpenFMB pre-configured
3.	Multiple field agents connected and communicating via OpenFMB
4.	Optimizer Pre-configured
5.	Control Portal Pre-configured
6.	RTDS is Active
7.	Network Model with Switchable Devices (2 Circuits)
8.	Tie Switch (Tie SW) is Closed
9.	Cap 1 is Close
10.	Cap 2 is Close
11.	R-1 is Closed
12.	VR-1 is Auto
13.	SW-1 is Closed
14.	Control Portal displays measurement values
15.	R-2 is Closed

9.5 Test Case Test Steps – UC 3b Peer-to-Peer Volt/Var Control

Steps	*Description*	*Acceptance Criteria*	*Pass / Fail*
#	*Step Description*	*Describe Acceptance Criteria*	*Pass (P) / Fail (F)*
1.	Var load on the feeder is increased above the setting threshold.	CB-A VAR load increased by simulation	3.2 MVAr to 4.2 MVAr
2.	CB-A Monitors network - determines Var above threshold	High Var Alarm	Pass
3.	CB-A issues a signal (High Var) to Optimizer for VAR support	CB-A sends High Var message	Pass
4.	Optimizer Receives message	High Var message received	Pass
5.	Optimizer sends command VR-1 to manual mode	VR-1 change status to Manual	Pass
6.	Control Portal Displays measurement values	CP displays measurement values	4.1 MVAr

9.6 Test Case Results – UC 3b Peer-to-Peer Volt/Var Control

Operational:

In this use case, the TIE breaker connecting Feeder A and part of Feeder B together is closed and an Over VAR threshold is exceeded at the Breaker A relay. To mitigate this situation, the Breaker A relay, having first closed Capacitor 1 on Feeder A, then proceeds to close Capacitor 2 on Feeder B using inter-network communication. Figure 3b-1 (below) shows the sequence of operation from the TIE breaker closing to the increase in VARS to Capacitor 2 closing and slightly decreasing VARS on the entire line. Note that there is a time delay between the TIE breaker closing and VARS rising. This delay is due to the fact that the relay only updates Watt and VAR calculations once every cycle as the calculation spans 1 cycle.

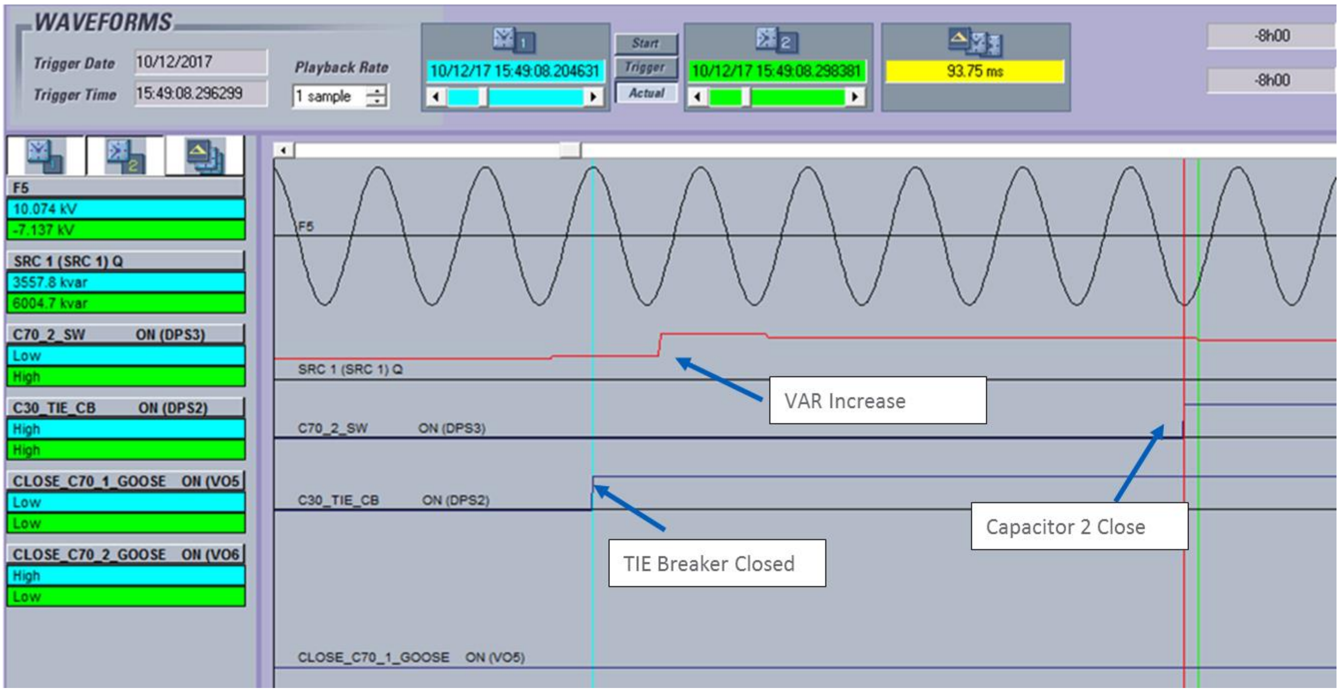


Figure 3b-1

Inter-Network VAR Control

Communication Observations:

The R-GOOSE message was used to send the CLOSE message to Capacitor 2. Of communication significance in this use case is that the message had to transit through a set of routers to get from the network for Feeder A to the network for Feeder B. The subscription for Capacitor 2 was initiated by an Internet Gateway Management Protocol (IGMP) “join” request from Capacitor 2. The request is shown in figure 3b-2 (below)

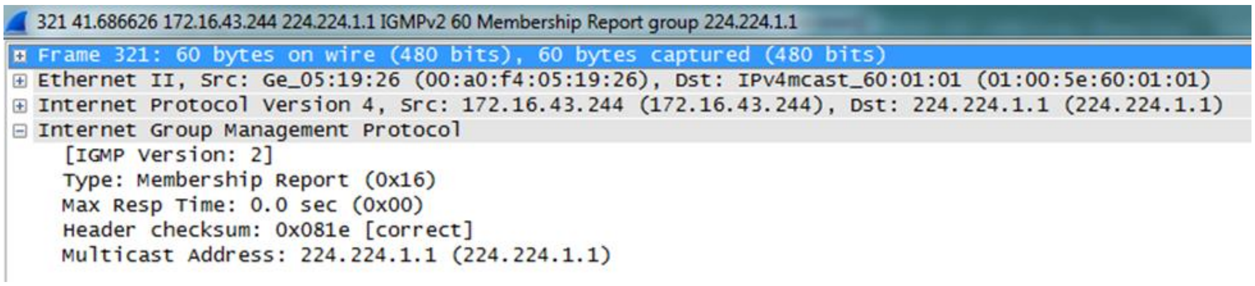


Figure 3b-2

“Join” Request from Cap Bank 2 (Network 43) Controller to the Feeder Controller (Network 42)

OpenFMB Gaps

Since MQTT uses a Broker to receive and re-transmit a message, the function of searching for a Multicast publisher is not needed, however, DDS can operate in a Multicast mode and can operate in this mode and use IGMP. Relating to Dynamic Subscription, if DDS can selectively enable and disable IGMP then a connection can be made on demand – and thus support Dynamic Subscription. In as much as MQTT is always point-to-point, routing to a new node can be accommodated as needed.

Recommendations

Do evaluate the ability of DDS to dynamically enable/disable Multicast subscription through the enabling and disabling of IGMP Join requests.

10 Test Case 4a – DER Active Power Control

10.1 Test Case Description – UC 4a DER Active Power Control

UC 4a DER Active Power Control

Objective:

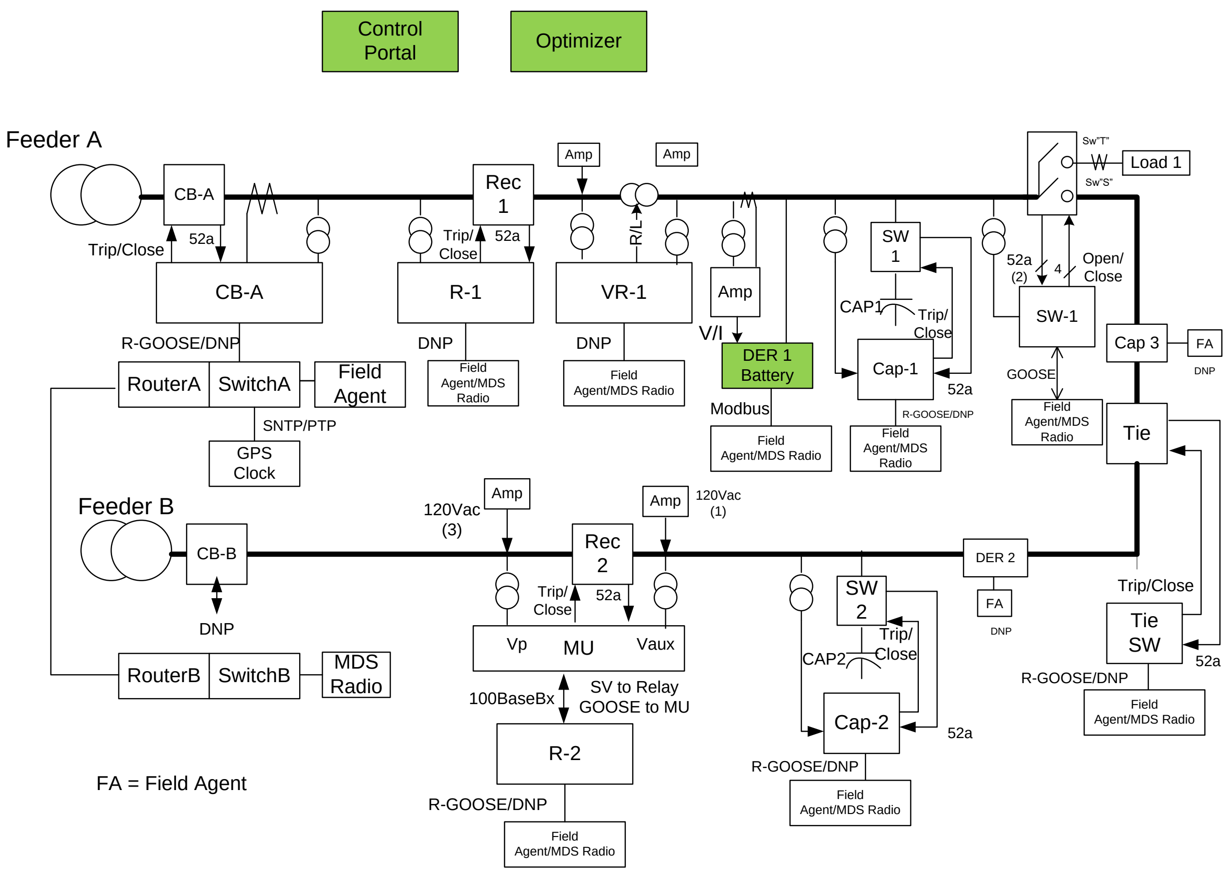
- Demonstrate the capability of OpenFMB using Modbus communication
- Demonstrate the interoperation of traditional IED's and DER using OpenFMB

Description:

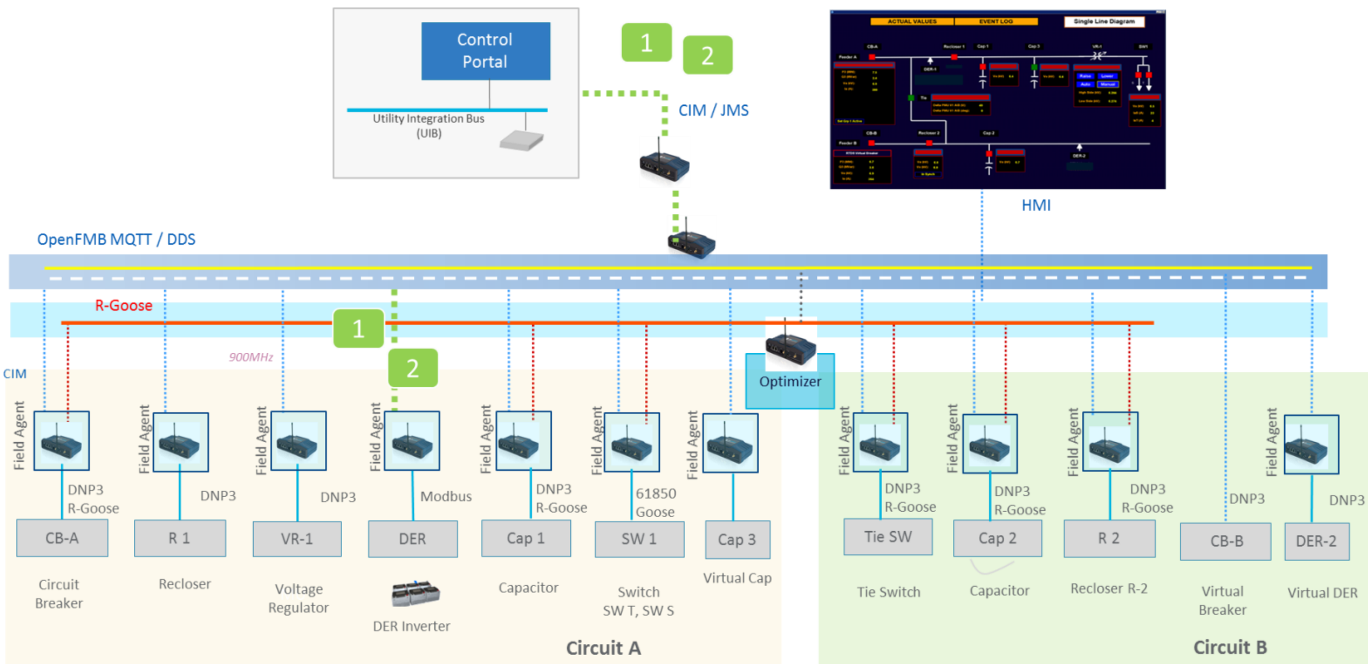
- The DER 1 inverter is to be connected into the RTDS with appropriate digital interface.
- A start command will be sent from the Control Portal to DER 1
- Operator to issue enable set point command. Enter value in the Heartbeat field
- Operator issues Real Power setpoint. Enter value in Active Power field
- Operator issues Reactive Power setpoint. Enter value in Reactive Power field
- Operator issues new High-Level Control Mode – Voltage Droop Reg. (Volts/Watts). Enter value in VoltControlMode field
- Operator issues new High Level Control Mode – Voltage Droop Reg. (Volts/Vars). Enter value in VoltControlMode field
- Test Engineer removes Ethernet connection to DER 1
- Test Engineer to re-connect Ethernet
- Operator issues reset command to DER 1 via Control Portal
- Operator to Open Breaker A and the response of the DER 1 will be recorded.

10.2 Test Case Diagram – UC 4a DER Active Power Control

Logical and IO Diagram



10.3 Test Case Diagram – UC 4a DER Active Power Control



Data Flow	Data Flow Summary	Protocol
1.	Control Portal → DER 1	Control Portal → OpenFMB(MQTT) → Field Agent → Modbus → DER 1 Inverter → Enable Start
2.	Control Portal → DER 1	Control Portal → OpenFMB(MQTT) → Field Agent → Modbus → DER 1 Inverter → Enable Joint Power/Reactive Power Set-point change
3.	Control Portal → DER 1	Control Portal → OpenFMB(MQTT) → Field Agent → Modbus → DER 1 Inverter → change Modes
4.	Control Portal → DER 1	Control Portal → OpenFMB(MQTT) → Field Agent → Modbus → DER 1 Inverter → Reset command
5.	Control Portal → DER 1	Control Portal → OpenFMB(MQTT) → Field Agent → Modbus → DER 1 Inverter → Enable Stop

10.4 Test Case Pre-Conditions – UC 4a DER Active Power Control

Pre-Conditions	*Description*
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	OpenFMB pre-configured
3.	Multiple field agents connected and communicating via OpenFMB
4.	Optimizer Pre-configured
5.	Control Portal Pre-configured
6.	Network Model with Switchable Devices (2 Circuits)
7.	Tie Switch (TIE SW) is Open
8.	Cap 1 is Close
9.	Cap 2 is Close
10.	R-1 is Closed
11.	VR-1 is Auto
12.	SW-1 is Closed (2 positions)
13.	Control Portal displays measurement values
14.	R-2 is Closed
15.	DER inverter or Simulator has heartbeat
16.	On Power-up of the DER 1 and Field Agent, the following registers shall be WRITTEN as part of initialization via the Control Portal: 40003 – 2 – START (Enter 1 CP Switch Position) 40007 – 2 – RESET 40008 – 2 – Set Voltage Source Inverter – PQ Mode 40009 – 100 – Initial Real Power Set Point 40101 – 256 – Set for Voltage / Watt mode of operation 40010 – 50 – Initial Reactive Power Set Point

10.5 Test Case Test Steps – UC 4a DER Active Power Control (Old)

Steps	*Description*	*Acceptance Criteria*	*Pass / Fail*
#	*Step Description*	*Describe Acceptance Criteria*	*Pass (P) / Fail (F)*
1.	Start Control Portal	Check the Control Portal & logs to verify the OpenFMB is up running	P
2.	Start Field Agents	Check the log and verity Field Agents are up running. The measurement value shall be published and have values.	P Measurement values are displayed
3.	Operator issues start command via Control Portal Enter 1 in Switch Position field	Verify the DER 1 is On-Line by looking at status on DER 1 HMI Capture Wire Shark	P, PCAP: Use Case 4a DER On
4.	Operator to issue enable set point command. Enter 96 in the Heartbeat field	Verify settings change on DER 1 HMI	F, Heartbeat value of 96 mapped to PQControlMode 96. Use Case 4a Set Heartbeat 96 Fail. Nothing changed on DER HMI.
5.	Operator issues Real Power setpoint (12kW) Enter 12 in Active Power field	Verify Real Power setpoint on DER 1 HMI is changed to 12 Capture Wire Shark Observe new power flow in RSCAD	P, Use Case 4a Set Point Power 12
6.	Operator issues Reactive Power setpoint (5kVAR) Enter 5 in Reactive Power field	Verify Reactive Power setpoint on DER 1 HMI is changed to 5 Capture Wire Shark	P, Use Case 4a Change VARS 5

Steps	*Description*	*Acceptance Criteria*	*Pass / Fail*
7.	Operator issues new High Level Control Mode – Voltage Droop Reg. (Volts/Watts) Enter 256 in VoltControlMode field	On DER 1 HMI verify Voltage Droop Reg. (Volts/Watts) Status is On Capture Wire Shark	F, VoltControlMode value 256 mapped to PQControlMode field on the Control Portal. Use Case 4a Set Volts-Watts 256; Use Case 4a Set Volts-Watts 256 Fail. Nothing changed on the DER HMI.
8.	Operator issues new High Level Control Mode – Voltage Droop Reg. (Volts/Vars) Enter 192 in VoltControlMode field	On DER 1 HMI verify Voltage Droop Reg. (Volts/Vars) Status is On Capture Wire Shark	F, VoltControlMode value 192 was mapped to PQControlMode field on the Control Portal. Use Case 4a Set Volts-VAR Fail. Nothing changed on the DER HMI.
9.	Test Engineer removes Ethernet connection to DER 1	Verify communication loss error on DER 1 UI	Inconclusive. Since we can't set PQ Enabled cannot determine loss of communications.
10.	Test Engineer to re-connect Ethernet	Re-connection established	P
11.	Operator issues reset command to DER 1 (40007-2) via Control Portal	Verify communication loss error reset	N/A
12.	Operator to Open Breaker A	DER 1 response is recorded via Oscillography	P, Stop Watch timing = 1 second. Wire Shark: Use Case 4a Trip Breaker A. Oscillography: Use Case 4a Trip Breaker A.cfg

10.6 Test Case Results – UC 4a DER Active Power Control

Operational:

In Use Case 4, an OpenFMB adapter was used to interface with a Modbus-based DCS on a Distributed Energy Device. The Edge Device – upon receiving an OpenFMB request – issued the equivalent Modbus READ message. An example of a Modbus Read is shown in figure 4a-1 (below).

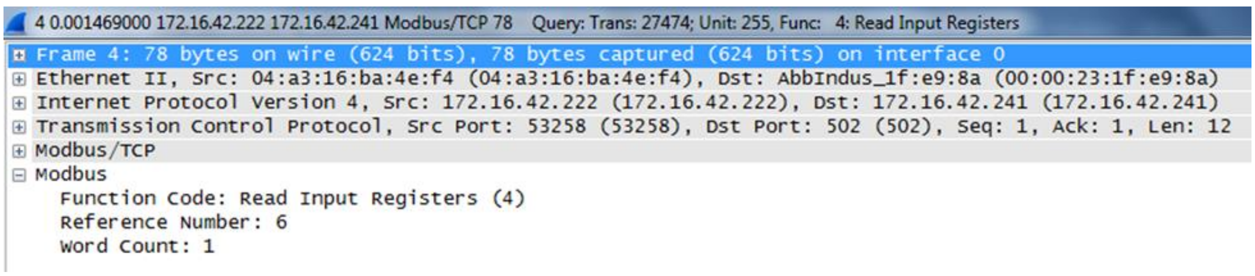


Figure 4a-1

DCS Register 40007 READ Command

One of the Use Case tests was to write a VAR set-point. Figure 4a-2 (below) is the Modbus Write to the VAR Set-Point register (40010). From the figure, one can see the value of 5kVAR being written into this register.

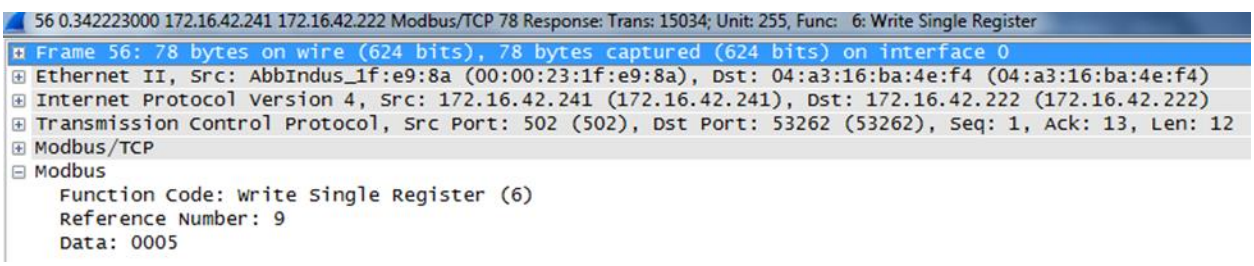


Figure 4a-2

Value Being Written into the VAR Set-Point Register

The MQTT message is encoded in XML and was captured in the related WireShark trace.

The ability to Write and Read the Watt and Var setpoints was demonstrated. The DER required a Heartbeat signal (a register write every 1 second). The Heartbeat was established through a Rule in the Optimizer. Due to the inability of the Control Portal to write to certain registers (PQ Mode and Volt/Watt-Volt/Var Mode), testing was never able to verify the efficacy of the Heartbeat. In addition, it was found that writing to one register in the Control Portal would result in the value showing up on another register (see Test results for exact behavior).

Communication Observations:

Overall Read/Write performance to the DER Edge was fast – on the order of 1 second which is quite adequate for a HMI response time. Of note, MOST DER devices (specifically, Solar inverters) presently use Modbus for device interface. The functionality of this edge protocol is important for inter-action with future DER devices

OpenFMB Gaps:

No OpenFMB gaps were identified in this use case.

Recommendations:

The Modbus registers required for interaction with the DER were mapped through the Control Portal and into the Edge Devices and only the programmed registers were accessible. It would be very desirable to have a “generic” Modbus interface such that any register address could be entered into the on-line system in order to peek and poke values into other useful Modbus registers.

11 Test Case 5a – DER on Line / off-line

11.1 Test Case Description – UC 5a DER on Line / off-line

UC 5a DER on Line / off-line

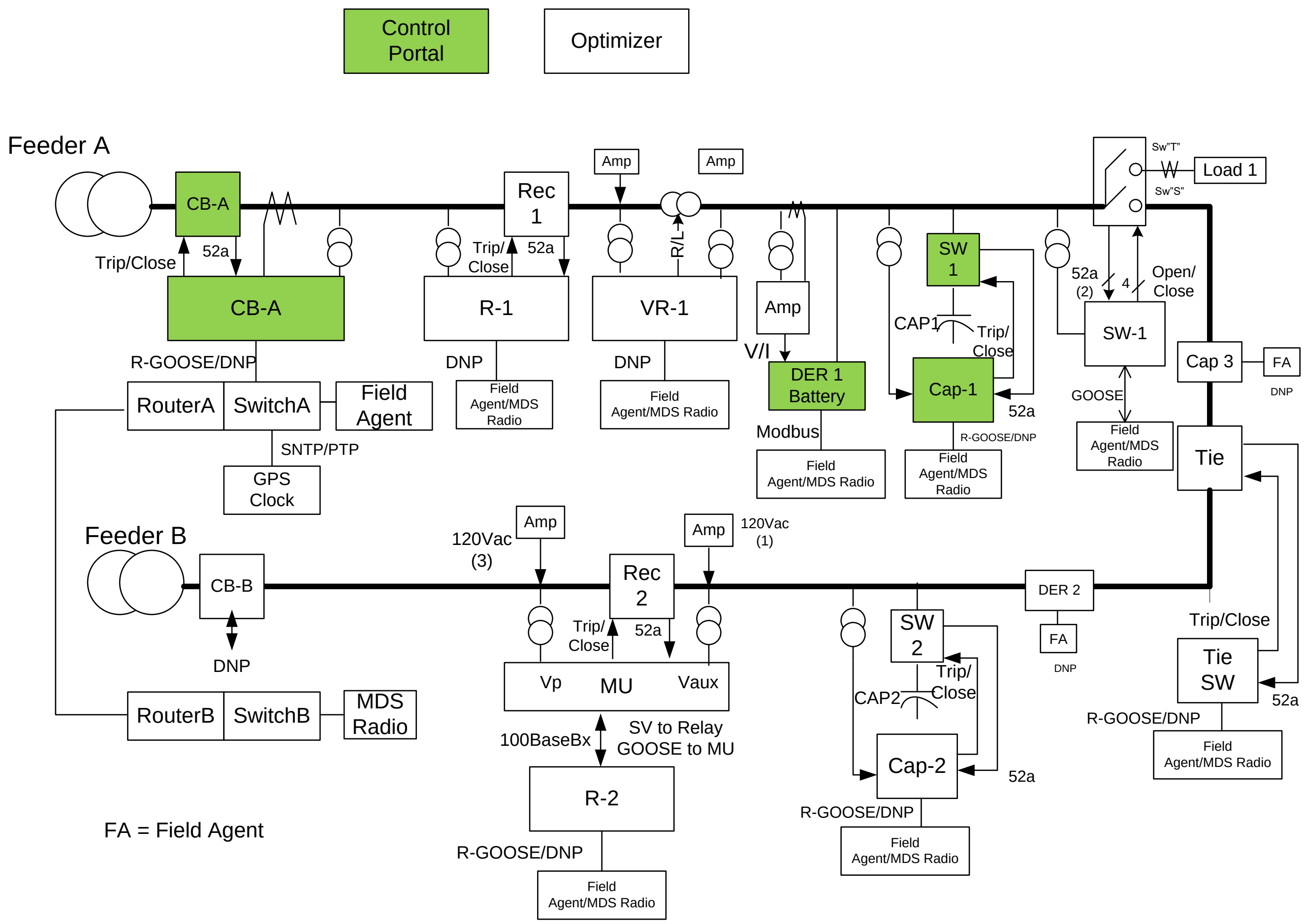
Objective:

- Demonstrate use of R-Goose to improve system performance by communicating breaker status to DER 1 and thereby over-riding autonomous DER control functions.

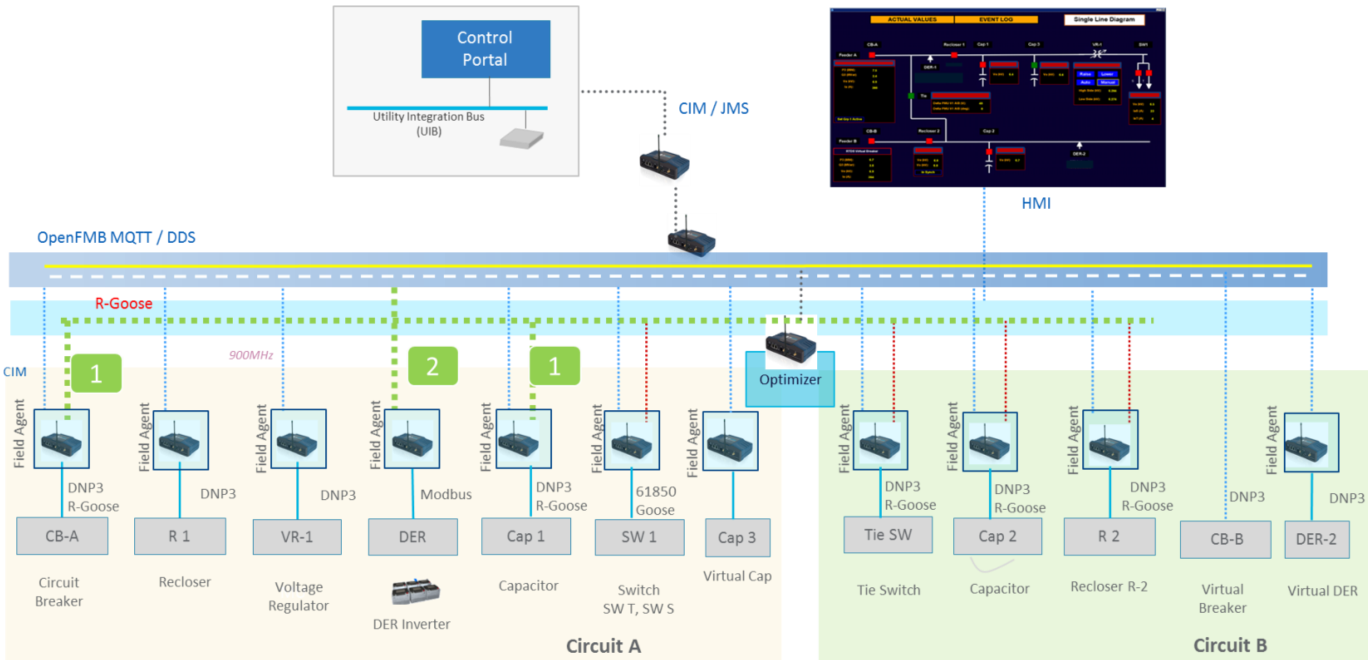
Description:

- To demonstrate enhanced DER 1 on-line/off-line via peer to peer
- Pushbutton on CB-A opens CB-A
- Upon detection of Breaker A open, CB-A sends a command to CAP 1.
- CAP 1 operates an output contact to take the DER 1 off-line
- Note: Present implementation of OpenFMB operates at speeds slower than the present disconnect speed of the DER 1.

11.2 Test Case Diagram – UC 5a DER on Line / off-line



11.3 Test Case Diagram – UC 5a DER on Line / off-line



Data Flow	*Data Flow Summary*	*Protocol*
1.	CB-A → CAP 1 → DER 1 Inverter	CB-A → R-GOOSE → CAP 1 → Contact Output → DER 1 Inverter

11.4 Test Case Pre-Conditions – UC 5a DER on Line / off-line

Pre-Conditions	*Description*
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	OpenFMB pre-configured
3.	Multiple field agents connected and communicating via OpenFMB
4.	Optimizer Pre-configured
5.	Control Portal Pre-configured
6.	Network Model with Switchable Devices (2 Circuits)
7.	Tie Switch (TIE SW) is Open
8.	Cap 1 is Close
9.	Cap 2 is Close
10.	R-1 is Closed
11.	VR-1 is Auto
12.	SW-1 is Closed (2 positions)
13.	Control Portal displays measurement values
14.	R-2 is Closed
15.	DER inverter or Simulator has heartbeat with RTDS with appropriate amplifier
16.	CB-A is Closed
17.	DER inverter set to maximum zero voltage ride thru

11.5 Test Case Test Steps – UC 5a DER on Line / off-line

Steps	*Description*	*Acceptance Criteria*	*Pass / Fail*
#	*Step Description*	*Describe Acceptance Criteria*	*Pass (P) / Fail (F)*
1.	Pushbutton on CB-A to open CB-A	Pushbutton command to open CB-A	P; Use Case 5a RGOOSE Trip of DER
2.	CB-A De-Energizes Feeder A	Feeder CB-A De-energized - Load side measurement values = zero	P
3.	Upon detection of Breaker A open, CB-A sends a command to CAP 1.	CB-A Sends a command to CAP 1	P
4.	CAP 1 operates an output contact to take the DER off-line	CAP 1 Output Contact operates	P
5.	DER 1 operates and goes off line	DER 1 disconnects from Grid	P

11.6 Test Case Results – UC 5a DER on Line / off-line

Operational:

In this use-case, when a Breaker A OPEN condition was detected, an R-GOOSE message was sent from the Feeder A relay to the Capacitor 1 Controller (which, for this test, was assumed to be in the same location as the DER). An Output Contact from the Capacitor 1 Controller was connected to the TRIP input of the DER. Figure 5a-1 shows the oscillography from the capacitor controller (nearby monitoring device). It can be seen in figure 5a-1 that the DER, upon detection of loss of voltage, instantly goes into shut-down. What can also be seen is that the STOP command was issued in 10 ms after Breaker A was opened.

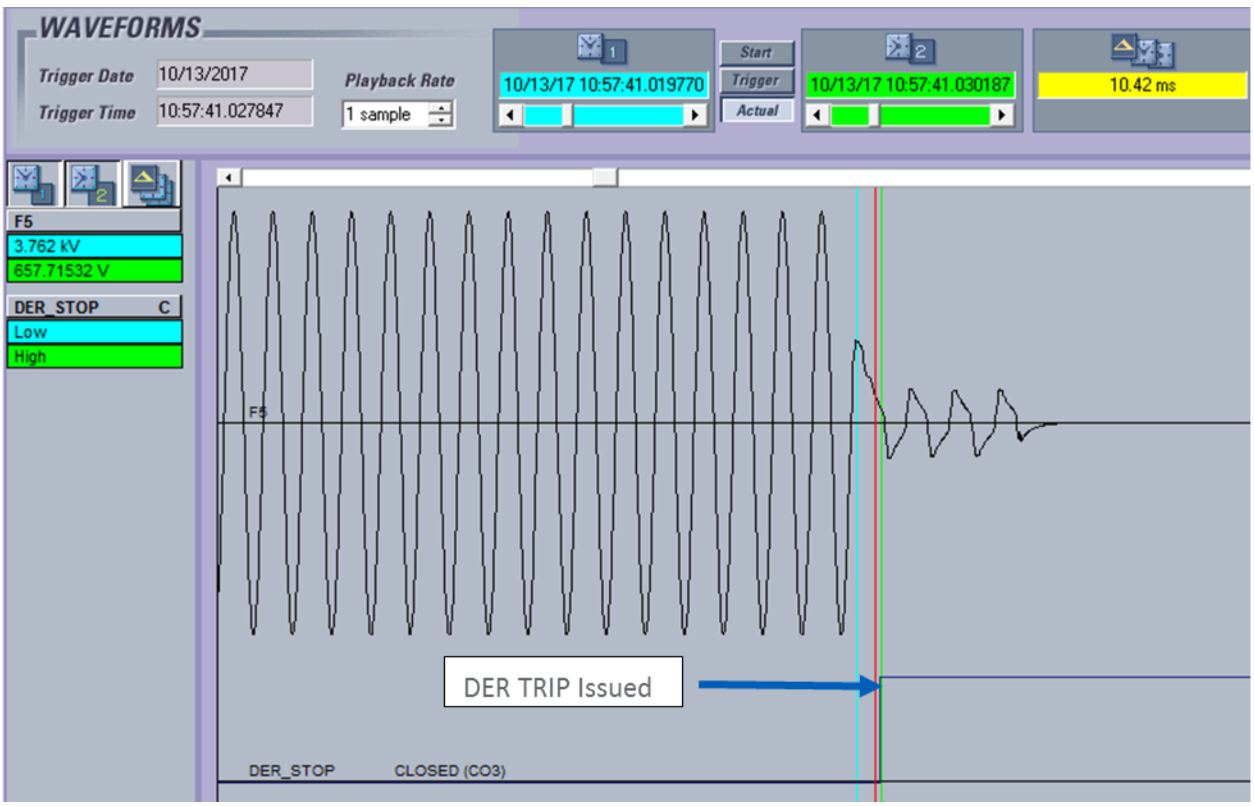


Figure 5a-1

DER Turn-off after Breaker A Open

Communication Observations:

The performance of the R-GOOSE message to trip the DER is quite notable – given that communications was through a pair of radios. Subtracting the 3ms operate time of the output contact, the TRIP input to the DER was transmitted from the Feeder Relay to the Capacitor Relay in 7ms.

OpenFMB Gaps:

For this project, the OpenFMB interface to the Edge device was through a Field Agent / Protocol Translator. When operating in this mode, the translation and encoding process increased the latency of the message to slightly over 1 second. When operating in protection control modes (e.g. – taking the DER off-line), this latency often exceeds the required performance limits. In the case of a DER, given that there is mandated ride-through time of 200ms (typical) of the inverters on the grid, it is then desirable to be able to force a DER off-line in the 1 to 2 cycle range. To achieve this goal, imbedded OpenFMB implementations will be required.

Recommendations:

Embedded OpenFMB implementations with sub-cycle performance are required for protection-based device-to-device communications. It is to be noted that the broker in the MQTT solution, even if embedded, would double the performance delay. Such applications may be better suited for the application of DDS which does not have to operate with a broker.

12 Test Case 6a – Enhanced Automatic Feeder re-deployment

12.1 Test Case Description – UC 6a Enhanced Automatic Feeder re-deployment

UC 6a Enhanced Automatic Feeder re-deployment

Objective:

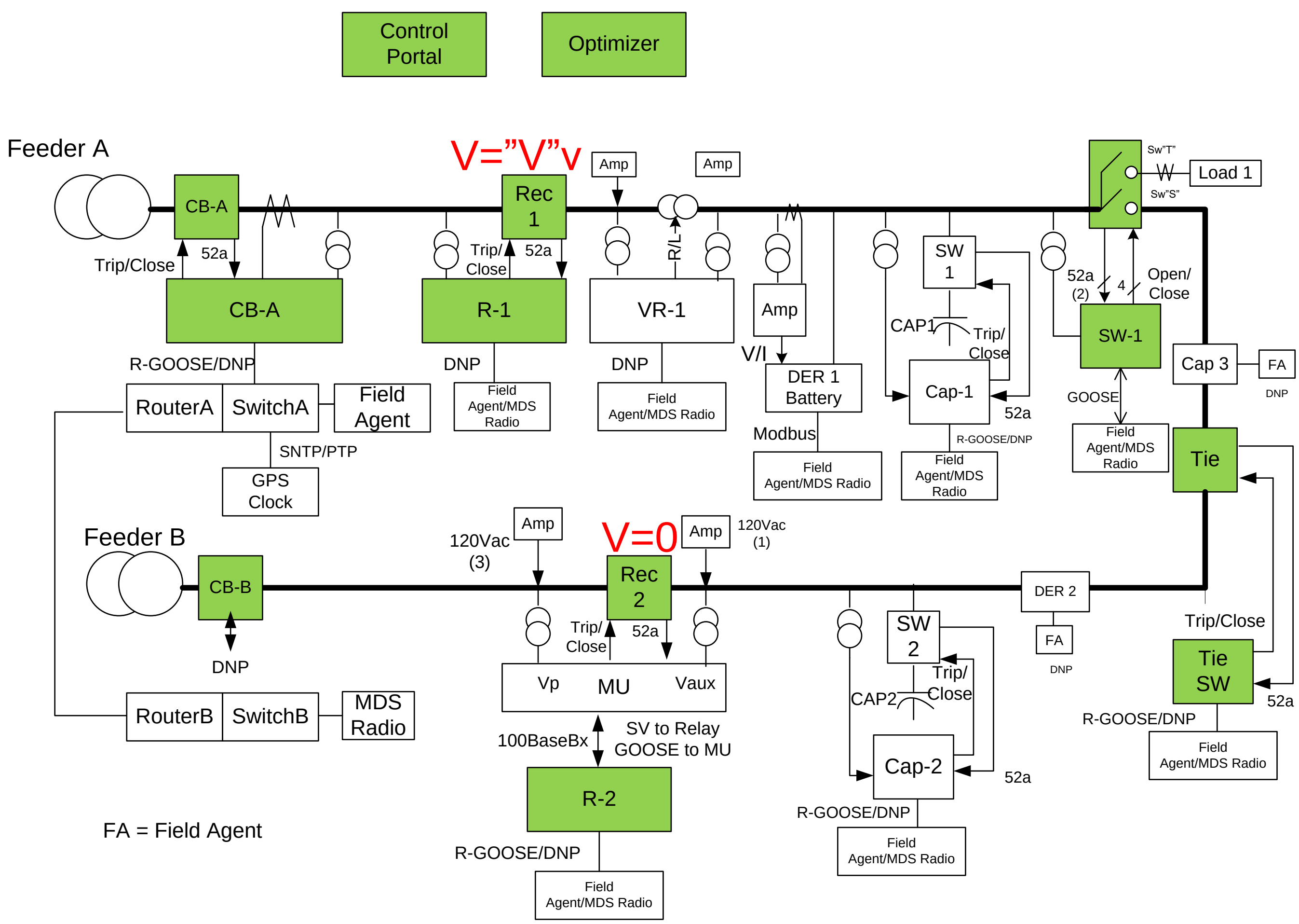
- Demonstrate the mapping of data from GOOSE messages into OpenFMB as well as complex inter-device communication.

Description:

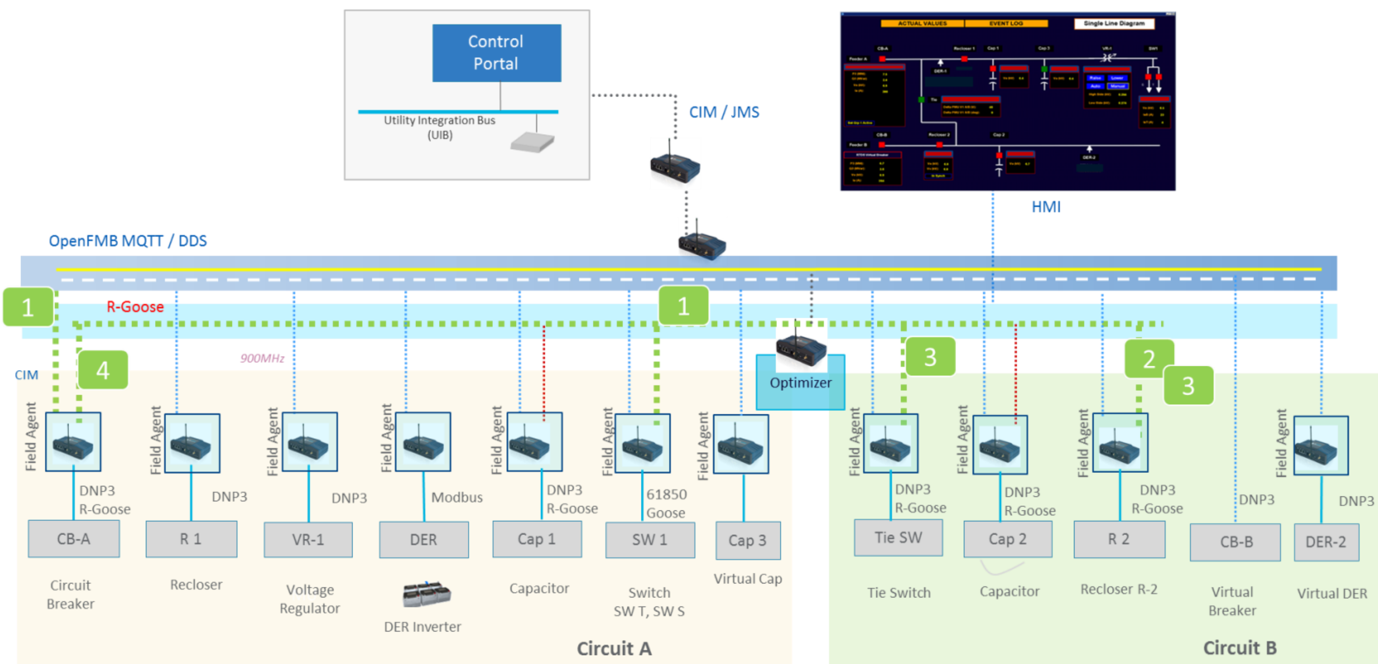
- *Healthy Feeder:*
  - If voltage on the breaker side of Recloser 2 is zero
  - AND there is voltage on Recloser 1 (PT to be located on the Line side of breaker A)
  - AND the feeder is configured for automatic re-deployment (Auto-reconfiguration Push-button on CB-A set to ENABLE)
  - AND the Feeder current (check on Phase A only) is BELOW the re-deployment threshold, the Healthy Feeder A Voltage status bit is set
- *Load Shed:*
  - If voltage on the Breaker side of Recloser 2 is zero
  - AND there is voltage on Recloser 1 AND the feeder is configured for automatic re-deployment (Auto-reconfiguration Push-button on CB-A set to ENABLE)
  - AND the Feeder current (check on Phase A only) is ABOVE the re-deployment threshold, the status bit "Load Shed" (DNP mapped point) is set.
- Message:
  - *If the "Load Shed" DNP point from CB-A is set, an OPEN command is to be sent, via OpenFMB, to OPEN Switch "T" on SW-1 to shed load on the feeder.*
  - *The R-2 on Recloser 2, upon receipt of the "Healthy Feeder A Voltage" status then sends a TRIP command to open Recloser 2*
  - R-2 THEN sends a command to Close the Tie SW – effectively back-feeding the second segment of Feeder B.
  - The CB-A, upon detection of the Tie SW being closed, will change setting groups to Group 2.
- Note: Healthy Feeder A Voltage status is NOT set if the Phase A current is above a user-specified level. A Load needs to be modeled on Switch T; connection to the Tie SW is to be connected to Switch "S"

12.2 Test Case Diagram – UC 6a Enhanced Automatic Feeder re-deployment

Logical and IO Diagram



12.3 Test Case Diagram – UC 6a Enhanced Automatic Feeder re-deployment



Data Flow	*Data Flow Summary*	*Protocol*
1.	CB-B → Open Breaker→ R-2	CB-B → Open Breaker, R-2 voltage = 0
2.	CB-A → R-Goose → R-2 → Healthy Feeder message	CB-A → R-Goose → R-2 → Healthy Feeder Message →Trip Open R-2
3.	R-2 → close Tie SW	R-2 → R-GOOSE → Tie SW
4.	CB-A → OpenFMB → SW-1	CB-A → *"Load Shed"* Open SW T Command (DNP) → OpenFMB (MQTT → Field Agent → OPC UA →61850 Goose message → SW-1 "Open Switch T"
5.	CB-A → Healthy Feeder message → close Tie SW → energize Feeder A	CB-A → R-GOOSE → Tie SW → energize Feeder A
6.	CB-A → change setting group	CB-A → change setting group to 2

12.4 Test Case Pre-Conditions – UC 6a Enhanced Automatic Feeder re-deployment

Pre-Conditions	***Description***
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	OpenFMB pre-configured
3.	Multiple field agents connected and communicating via OpenFMB
4.	Optimizer Pre-configured
5.	Control Portal Pre-configured
6.	Network Model with Switchable Devices (2 Circuits)
7.	Tie Switch (TIE SW) is Open
8.	Cap 1 is Open or Closed
9.	Cap 2 is Open or Closed
10.	R-1 is Closed with Voltage > 0
11.	VR-1 is Auto
12.	SW-1 is Closed (S Switch & T Switch)
13.	Control Portal displays measurement values
14.	CB-B is Closed
15.	CB-A is Closed with Auto Re-deployment enabled
16.	Test Engineer to enable the CB-A Auto Re-deployment
17.	CB-A set over current threshold value IA = X (400 amps)
18.	Var Per Unit Condition = 2.5 MVAR; PU setting = 0.39 = 3.37 MVAR
19.	Voltage “OK” value = 0.9 PU

12.5 Test Case Test Steps – UC 6a Enhanced Automatic Feeder re-deployment

Steps	***Description***	***Acceptance Criteria***	***Pass / Fail***
#	*Step Description*	*Describe Acceptance Criteria*	*Pass (P) / Fail (F)*
1.	Start Control Portal	Check the Control Portal & logs to verify the OpenFMB is up running	P
2.	Start Field Agents	Check the log and verity Field Agents are up running. The measurement value shall be published and have values.	P Measurement values are displayed
3.	**“Healthy Feeder” UC 6a-1**		
4.	Test Engineer trips CB-B from HMI Note: CB-A Auto Re-Configuration Enabled Amplifiers turned on	Verify on HMI that CB-B is Open. Verify R-2 high side voltage = 0, voltage on Recloser 1 > 0	P CB-A = 252a increased to CB-A = 320a
5.	CB-A Phase A Current $\leq$ Threshold then the Healthy Circuit status issued	CB-A Current $\leq$ Threshold = Healthy Feeder	P
6.	CB-A Circuit A reconfiguration	Observe circuit reconfiguration CB-A Closes the Tie SW. Circuit re-configuration from CB-A to R-2.	P Screen Shot to be attached (Word document
7.	**“Load Shed” UC 6a-2**		
8.	Test Engineer trips CB-B from HMI Note: CB-A Auto Re-Configuration Enabled Amplifiers turned on	Verify on HMI that CB-B is Open. Verify R-2 high side voltage = 0, voltage on Recloser 1 > 0	P
9.	CB-A Phase A Current > Threshold then the “Load Shed status issued	CB-A Phase A Current $\geq$ Threshold = “Load Shed” Feeder A status	P
10.	CB-A sends “Load Shed” DNP point via OpenFMB to OPC UA (UAP) to SW-1 (T)	CB-A sends “Load Shed” → OPC UA (UAP) to SW-1 (T)	Fail OPC- UA issue
11.	CB-A Phase A Voltage $\leq$ Threshold then the Healthy Circuit status issued	CB-A Current $\leq$ Threshold = Healthy Feeder	Fail OPC- UA issue
12.	CB-A Circuit A reconfiguration	Observe circuit reconfiguration CB-A Closes the Tie SW	Fail OPC- UA issue
13.	CB-A detects Tie SW closed, change setting group	CB-A Changes Settings Group from 1 to 2. Observe setting group in actual values in CB-A.	Fail OPC- UA issue

12.6 Test Case Results – UC 6a Enhanced Automatic Feeder re-deployment

Operational:

In this use case, when the conditions for Feeder Re-deployment are met (Feeder 1 has voltage, load is low, and Recloser 2 has no voltage on the Breaker side), the feeder A IED sends a message to Recloser 2 – telling it to OPEN. Once OPEN, Recloser 2 then sends a message to the TIE Breaker controller to CLOSE the TIE. The WireShark capture (figure 6a-1) shows the FIRST in the sequence of R-GOOSE Transmissions that sets the "OK to Re-deploy" bit to "1" – which is subscribed-to by Recloser 2. Subsequently, Recloser 2 opens and then sends the CLOSE message to the TIE breaker controller. The expanded HMI screen in Figure 8 shows the state of the model system after these transactions. Of note, the Feeder A relay was re-configured to Setting Group 2 (because of the feeder re-configuration), the TIE breaker is CLOSED, and Recloser 2 is OPEN. Also, to be noted, is that the Voltage on the Breaker side of Recloser 2 is observed to be "0".

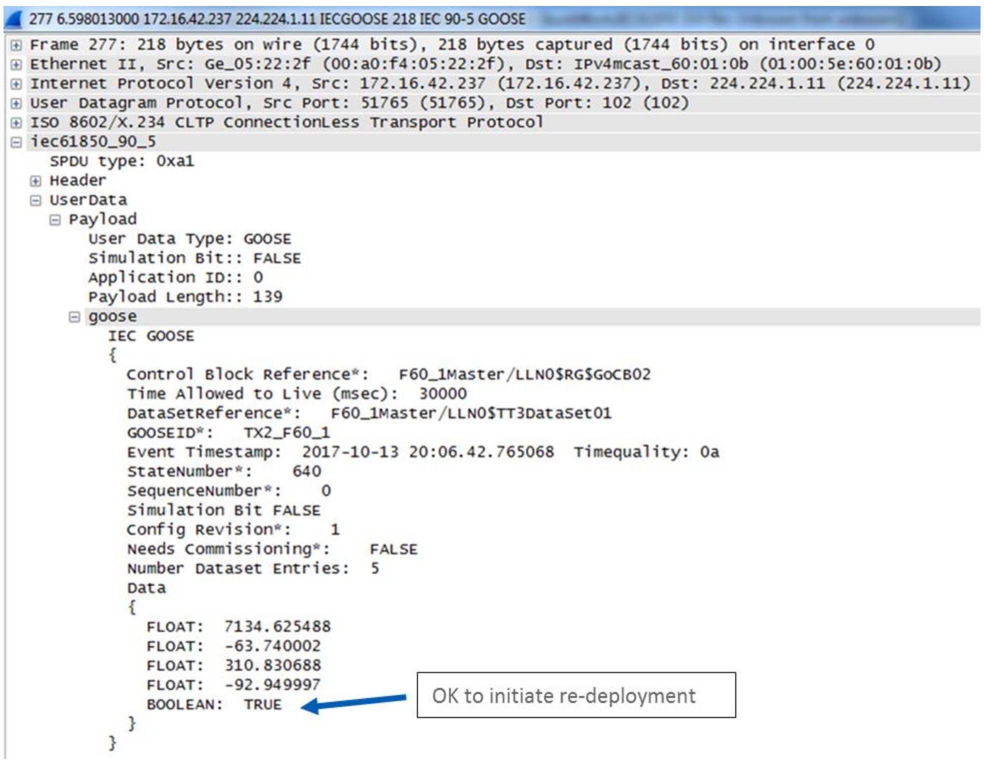


Figure 6a-1

"OK to Re-deploy" Message

The timing of the feeder re-deployment can be seen is figure 6a-2 (below). The time from loss of voltage (as detected by Recloser 2) and the remainder of the feeder being re-energized can be seen to be 245ms – less than ¼ of a second. It should also be noted that this use case requires inter-network communication.

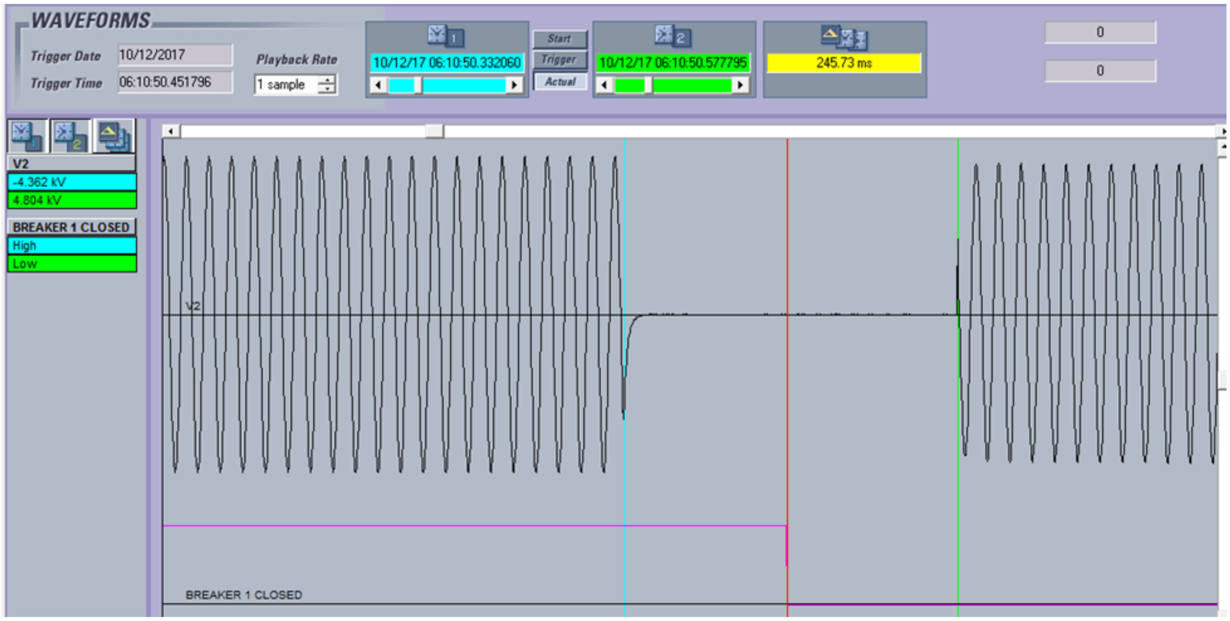


Figure 6a-2

Feeder Re-Energization Timing

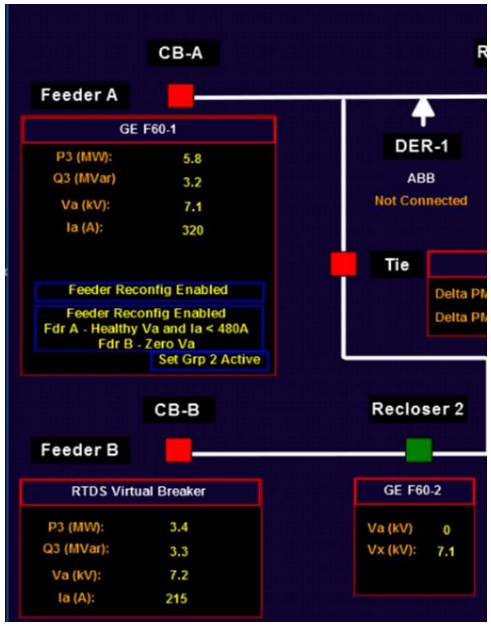


Figure 6a-3 Expanded HMI view after Feeder Re-deployment

In the re-run of Use Case 6a, the load on Feeder is increased and so the Feeder A relay sends an OpenFMB message to the Feeder Switch to Shed Load. In as much as the OPC-UA interface could not be implemented, the load was not shed, however, we note that the “OK to Re-deploy” bit from the Feeder A relay stays “FALSE” (figure 6a-4) below.

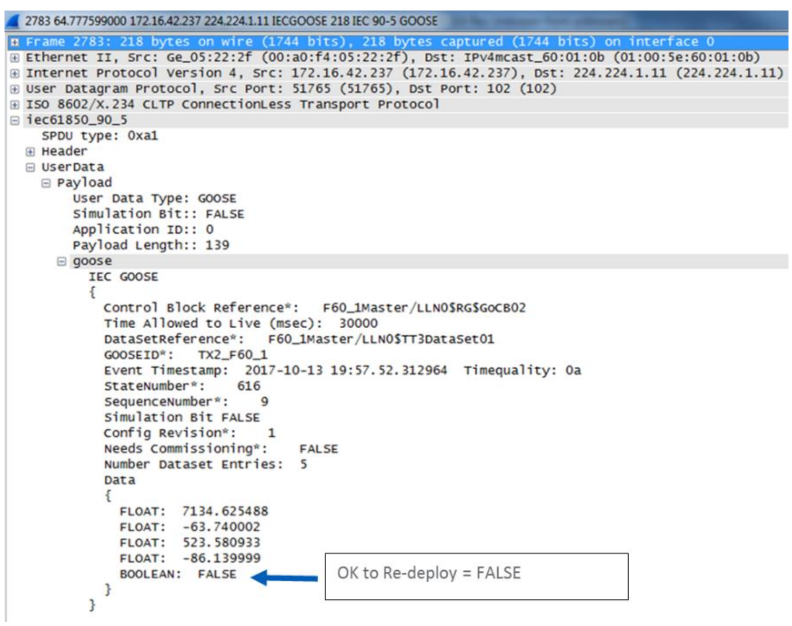


Figure 6a.4

NOT OK to Re-deploy

Communication Observations:

Device publication of GOOSE messages and the reception of these messages by 3rd party SW worked well, however, connection between the 3rd part SW and the Edge device via OP-UA proved problematic. To facilitate connection in the future, establishment of OPC-UA inter-operability test suites between clients and servers is recommended. Additionally, clear visibility into the plethora of configuration parameters and diagnostics to identify mis-matches between parameters should be developed. It is to be noted that WireShark does decode OPC-UA messages but does not provide mis-match analysis.

OpenFMB Gaps:

The gaps identified in this use-case are not OpenFMB related but more related to the need for tools to facilitate the interface between edge devices when performing protocol translation (see comments on Communication above).

Recommendations:

Better OPC-UA inter-operability tools to facilitate test and de-bug of OPC-UA interfaces are needed. A direct GOOSE to OpenFMB adapter is needed.

13 Test Case 7a – Automatic Feeder Re-Close

13.1 Test Case Description – UC 7a Automatic Feeder Re-Close

UC 7a Automatic Feeder Re-Close

Objective:

- Demonstration circuit re-configuration back to normal operating condition

Description:

- Precondition: Breaker B is Open and Recloser 2 is Open.

UC 7a -1 Inside the Limit

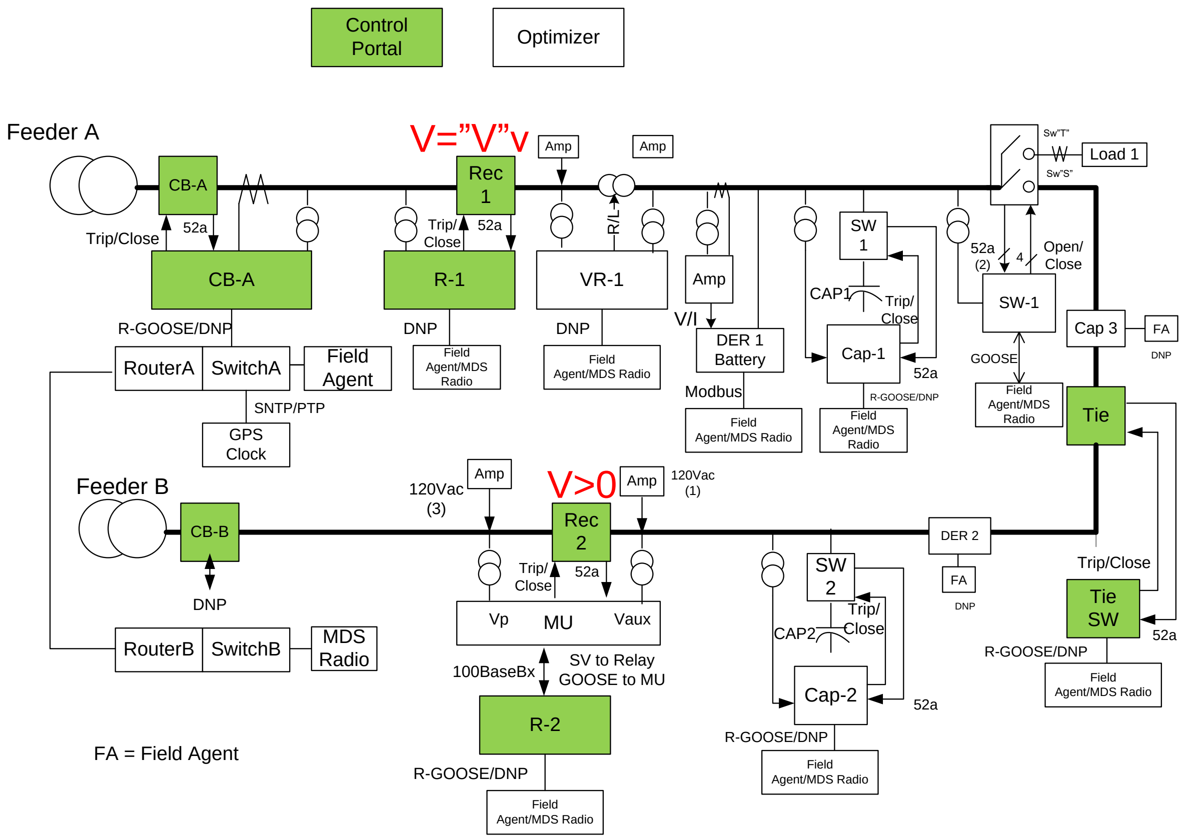
- Breaker B is then closed by RTDS / HMI – placing Voltage on the Breaker side of Recloser 2.
- Voltage is detected on both sides of the R-2 and the phase angle of the voltage across the recloser is less than 30 degrees (as measured by R-2)
- THEN reclose R-2 and Open the Tie SW from R-2.
- The CB-A identifies that the Tie SW is now open and changes back to the setting group 1.

UC 7a -2 Outside the Limit

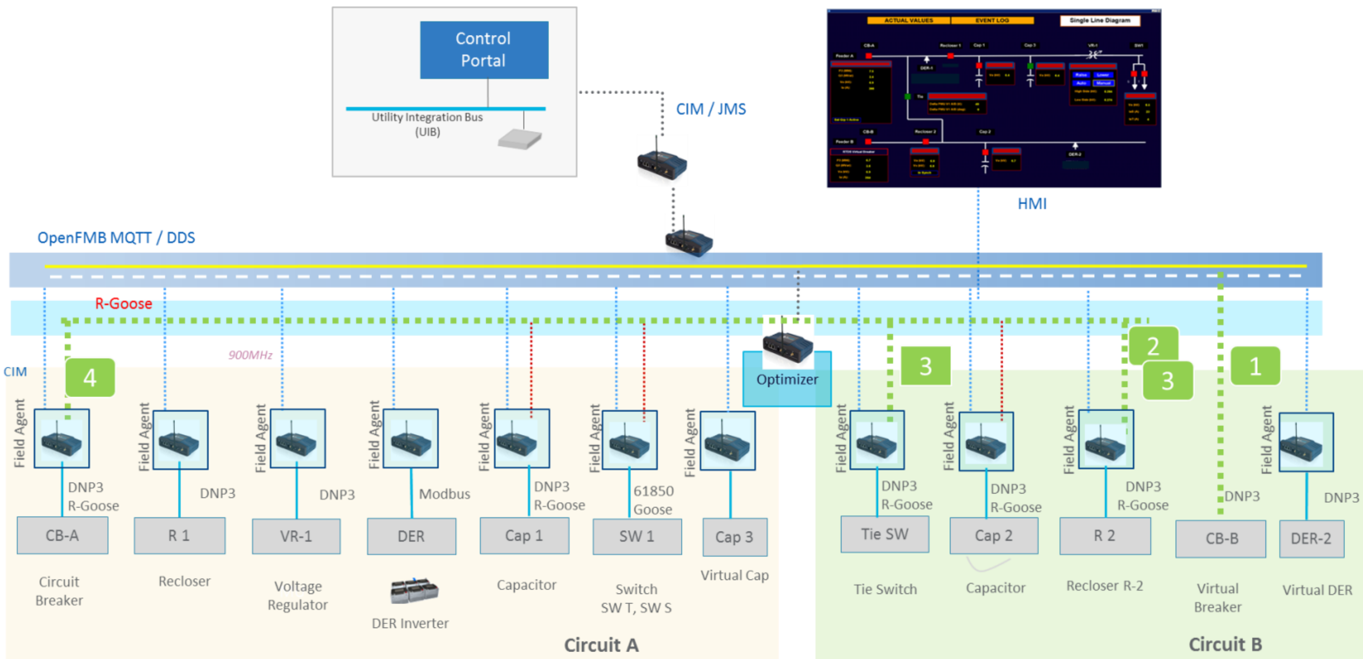
- Breaker B is then closed by RTDS / HMI – placing Voltage on the Breaker side of Recloser 2.
- Voltage is detected on both sides of the R-2 and the phase angle of the voltage across the recloser is = 45 degrees
- Tie SW - measure phase Angle (RTDS observes phase angle) Verify Sync check.
- Recloser 2 (R-2) status fails to close

13.2 Test Case Diagram – UC 7a Automatic Feeder Re-Close

Logical and IO Diagram



13.3 Test Case Diagram – UC 7a Automatic Feeder Re-Close



Data Flow	*Data Flow Summary*	*Sequence*
1.	RTDS Close CB-B	CB-B → Closed
2.	R-2 → Voltage ≥ 0 → Phase Angle ≤ 30 degree	R-2 → Voltage ≥ 0, Angle ≤ 30-degree Message R-GOOSE → Close R-2
3.	R-2 → Open Tie SW	R-2 → R-GOOSE → Tie SW
4.	CB-A → Feeder A (normal) → change setting group	Tie SW → R-Goose → CB-A → change setting group to 1
5.	R-2 → Voltage ≥ 0 → Phase Angle = 45 degrees	R-2 → Voltage ≥ 0, Angle = 45-degree → Fails to Close R-2

13.4 Test Case Pre-Conditions – UC 7a Automatic Feeder Re-Close

Pre-Conditions	*Description*
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	OpenFMB pre-configured
3.	Multiple field agents connected and communicating via OpenFMB
4.	Optimizer Pre-configured
5.	Control Portal Pre-configured
6.	Network Model with Switchable Devices (2 Circuits)
7.	Tie Switch (TIE SW) is Closed
8.	Cap 1 is Open or Closed
9.	Cap 2 is Open or Closed
10.	R-1 is Closed
11.	VR-1 is Auto
12.	SW-1 is Closed (2 positions)
13.	Control Portal displays measurement values
14.	R-2 is Open
15.	CB B is Open
16.	CB A is Closed

13.5 Test Case Test Steps – UC 7a Automatic Feeder Re-Close

Steps	*Description*	*Acceptance Criteria*	*Pass / Fail*
#	*Step Description*	*Describe Acceptance Criteria*	*Pass (P) / Fail (F)*
1.	Start Control Portal	Check the Control Portal & logs to verify the OpenFMB is up running	P
2.	Start Field Agents	Check the log and verity Field Agents are up running. The measurement value shall be published and have values.	P Measurement values are displayed
3.	**UC 7a -1 Inside the Limit**		
4.	Close CB-B from RTDS Note: CB-A Auto Re-Configuration Enabled, Amplifiers turned on	CB-B = Close. Verify on HMI, RTDS & Control Portal	P
5.	R-2 - measure voltage (High & Load) side. Check	R-2 – Monitor Voltage measurement	P
6.	R-2 - Recloser 2 - measure phase Angle (RTDS observes phase angle) Sync check passed.	Pre-condition Recloser Measurement value (Phase Angle) $\leq$ 30 degrees. Observe angle on F-60-2. Sync check passed.	P
7.	Close Recloser 2	R-2 status is closed	P
8.	R-2 sends Open command to Tie SW	Tie SW = Open	P
9.	CB-A Monitors Tie SW = Open and changes back to the original setting group (1)	CB-A Setting group change from 2 to 1 Verify setting group in actual value in CB-A	P File: 7a Feeder Reclose
10.	**UC 7a -2 Outside the Limit**		
11.	Close CB-B from RTDS Note: CB-A Auto Re-Configuration Enabled, Amplifiers turned on	CB-B = Close. Verify on HMI & RTDS	P
12.	R-2 - measure voltage (High & Load) side. Check	R-2 – Monitor Voltage measurement	P
13.	Tie SW - measure phase Angle (RTDS observes phase angle) Sync check passed.	Pre-condition Recloser Measurement value (Phase Angle) = 45 degrees. Observe angle on Tie SW. Sync check passed.	P
14.	Recloser 2 status	R-2 status fails to close	P

13.6 Test Case Results – UC 7a Automatic Feeder Re-Close

Operational:
In this use case, upon the closing of Breaker B, the process to return the system back to normal is initiated. Recloser 2 detects voltage on the Breaker side of the line and there is already voltage on the line side of the recloser (Tie is closed). This initiates a Check Sync request by Recloser 2. In figure 7a-1 (below), the Line and Bus voltages can be seen to be exactly in phase (±1°). Being in phase and having the magnitudes within 1000 volts of one another (an arbitrary setting), the reclosing of Recloser 2 is allowed. Once Recloser 2 is closed, Recloser 2 sends an R-GOOSE message to the Tie Breaker controller to open the tie. The TIE, upon opening, sends Tie Breaker Status message to Breaker A which then return to Setting Group 1. Of note in this use case is the ability to establish pub-sub relationships among any set of devices in the network of interest.

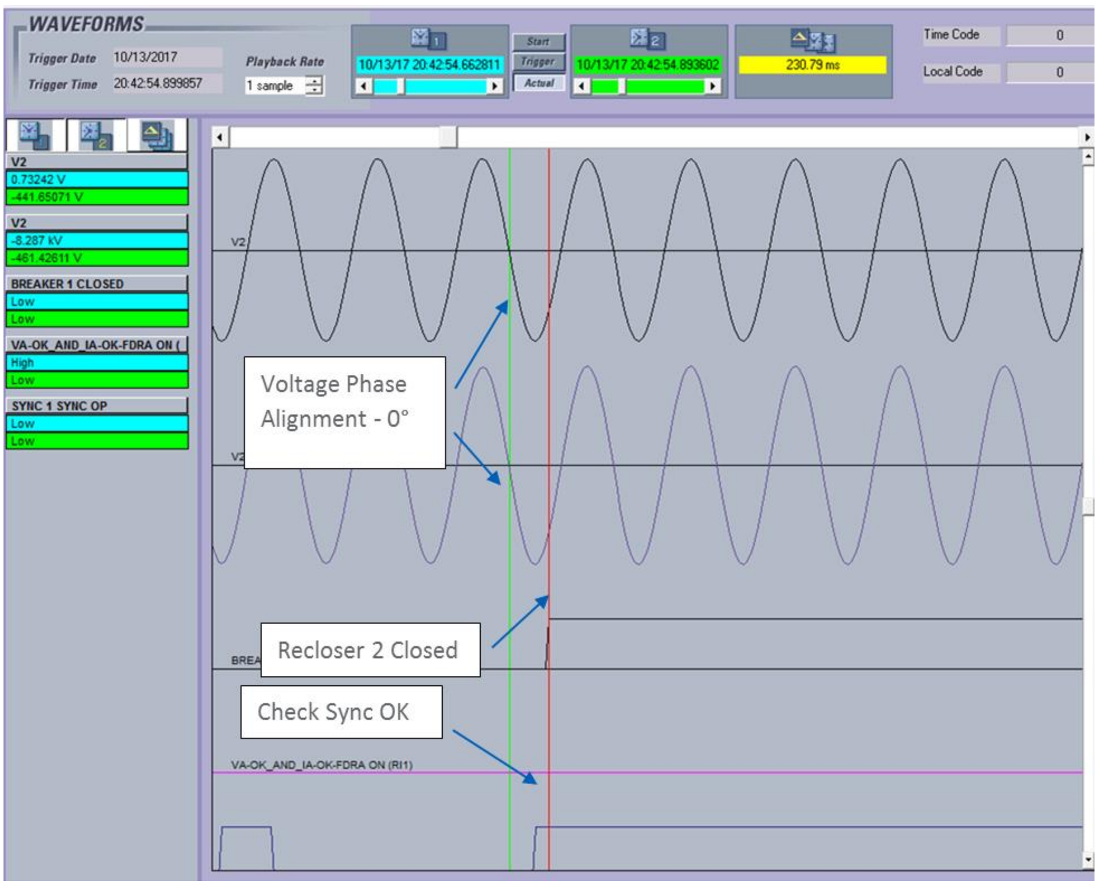


Figure 7a-1

0° Angular Difference between Line A and Line B

It is to be noted that the same test was run with a 45° phase angle difference (changing the phase angle of the source on Line B). With the phase angle difference across Recloser 2 greater than 30° (typical setting), the reclose request failed to reclose. Again, the angle as set by the analog simulator and the vs. the value read on the display was +/- 1°.

Communication Observations:

The message communication between Recloser B and the Tie breaker was performed via R-GOOSE with all messaging taking place on the Network B communication subnet. As an embedded implementation, launch times of the R-GOOSE message averaged 1ms from an event detection. With R-GOOSE, an event was either a change of a binary value in the message or a change in an analog value that is greater than the set deadband for the measurement.

OpenFMB Gaps:

Computation of the angular difference between the Bus and Line Side voltages highlights the need to be able to implement programmable logic in a device and the need for the logic to be inter-operable among manufacturers.

Recommendations:

The OpenFMB work group should investigate the adoption of the IEC 61131 standard to facilitate the inter-operability of logic among various vendors. It is also recommended that OpenFMB investigate the use of “change” events to launch OpenFMB messages. The OpenFMB WG should consider creating a standard mechanism for the mapping of analog values into OpenFMB messages.

14 Test Case 8a – Sample Value Test Cases (Documentation only)

14.1 Test Case Description – UC 8a Sample Value Test Cases (Documentation only)

UC 8a Sample Value Test Cases

Objective:

- Demonstrate the high-speed transmission of sample values as to further develop communication requirements for OpenFMB

UC 8a Sample Value Test Cases (Documentation only)

- The measurement and transmission of Voltage and Current values from field equipment is known as Sample Values. Sample Values (SV) typically require high sample rates in the range of 3000 to 96,000 samples per second. Additionally, the device creating the Samples (known as the Merging Unit) can be located several kilometers away. IEC61850 introduced the concept of Sample Values as a digital interface to Optical Current and Voltage sensors as well as application-specific circumstances where remote location of Voltage and Current sensors is required/desirable. The 61850 standard addresses issues such as data synchronization and phase correction. Given the high bandwidth and low latency constraints of such data, further study of its applicability to OpenFMB is needed.
- Note: extend the write-up to include RSV documentation
- Documentation included in the Final Report

15 Test Case 8b – Synchrophasors via R-Goose

15.1 Test Case Description – UC 8b Synchrophasors via R-Goose

UC 8b Synchrophasors via R-Goose

Objective:

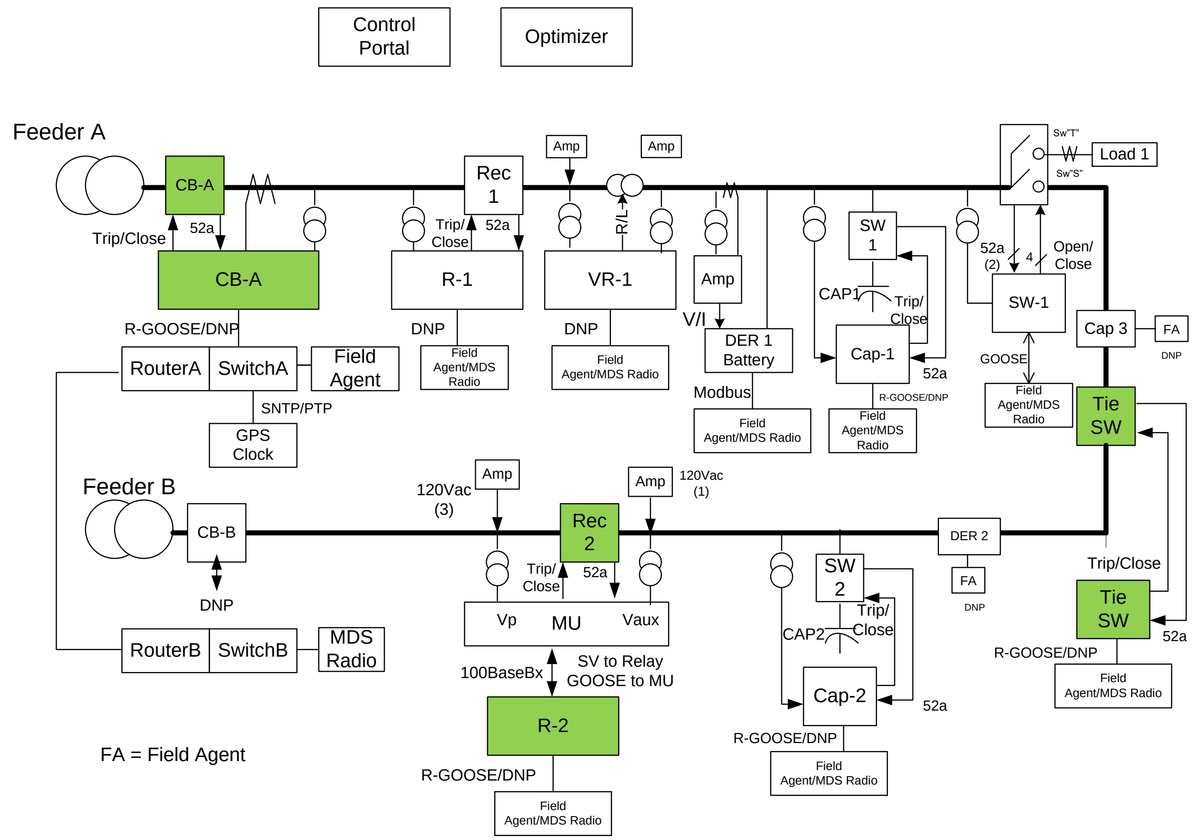
- Demonstrate the pub/sub of high speed data (e.g. synchrophasors) via routable GOOSE and evaluate the incorporation into OpenFMB standards.

Description:

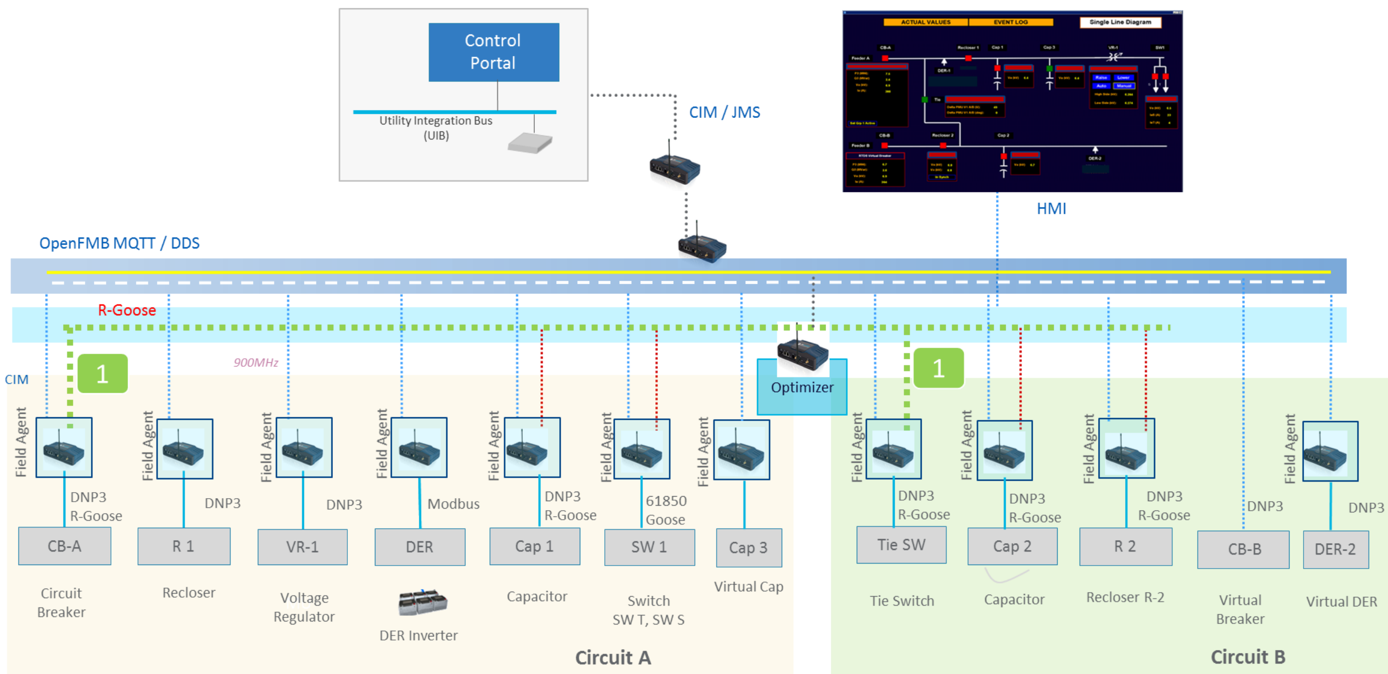
- Synchrophasors (V1 Magnitude and Angle) are to be mapped into Generic Analog 61850 data objects in CB-A and R-2 and then included in R-GOOSE messages.
- R-GOOSE reception by Tie SW.
- Tie SW commutes magnitude difference and angle difference
- Note: under evaluation – dynamic angle difference displayed on Tie SW

15.2 Test Case Diagram – UC 8b Synchrophasors via R-Goose

Logical and IO Diagram



15.3 Test Case Diagram – UC 8b Synchrophasors via R-Goose



Data Flow	*Data Flow Summary*	*Sequence*
1.	CB-A & R-2 send Synchrophasor data to Tie SW	F60 → R-Goose → Tie SW

15.4 Test Case Pre-Conditions – UC 8b Synchrophasors via R-Goose

Pre-Conditions	***Description***
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	Network Model with Switchable Devices (2 Circuits)
3.	Tie Switch (TIE SW) is Open
4.	Cap 1 is Open or Closed
5.	Cap 2 is Open or Closed
6.	R-1 is Closed
7.	VR-1 is Auto
8.	SW-1 is Closed (2 positions)
9.	Control Portal displays measurement values
10.	R-2 is Closed
11.	CB B is Closed
12.	CB A is Closed

15.5 Test Case Test Steps – UC 8b Synchrophasors via R-Goose

Steps	***Description***	***Acceptance Criteria***	***Pass / Fail***
#	*Step Description*	*Describe Acceptance Criteria*	*Pass (P) / Fail (F)*
1.	CB-A and R-2 send Synchrophasor data	Observe angle and magnitude difference on Tie SW	P
2.	Change source Voltage angle and magnitude between Feeder 1 & Feeder 2	Observe angle and magnitude change on Tie SW	P File: UC 8 Angle change

15.6 Test Case Results – UC 8b Synchrophasors via R-Goose

Operational:

To demonstrate the high-speed performance of the R-GOOSE transport, Synchrophasors (Voltage and Current Magnitude and Angle) were mapped into R-GOOSE datasets in the Feeder A relay and the Recloser 2 relay. The Tie Breaker controller was configured to subscribe to the R-GOOSE datasets from these two relays. Upon receipt in the controller, the values were sent to Magnitude and Angle difference functions. The differences in Magnitude and Angle were then displayed on the HMI and on the Control Portal. Although Synchrophasors are normally transmitted continuously, mapping the values into R-GOOSE AND configuring a tight deadband around the magnitude and angle values can result in transmission of Synchrophasor-based datasets every 100ms.

The R-GOOSE capture from Recloser 2 is shown in figure 8a-1 (below). In the dataset, the voltage Magnitude (first analog) and Voltage angle (second analog) can be observed.

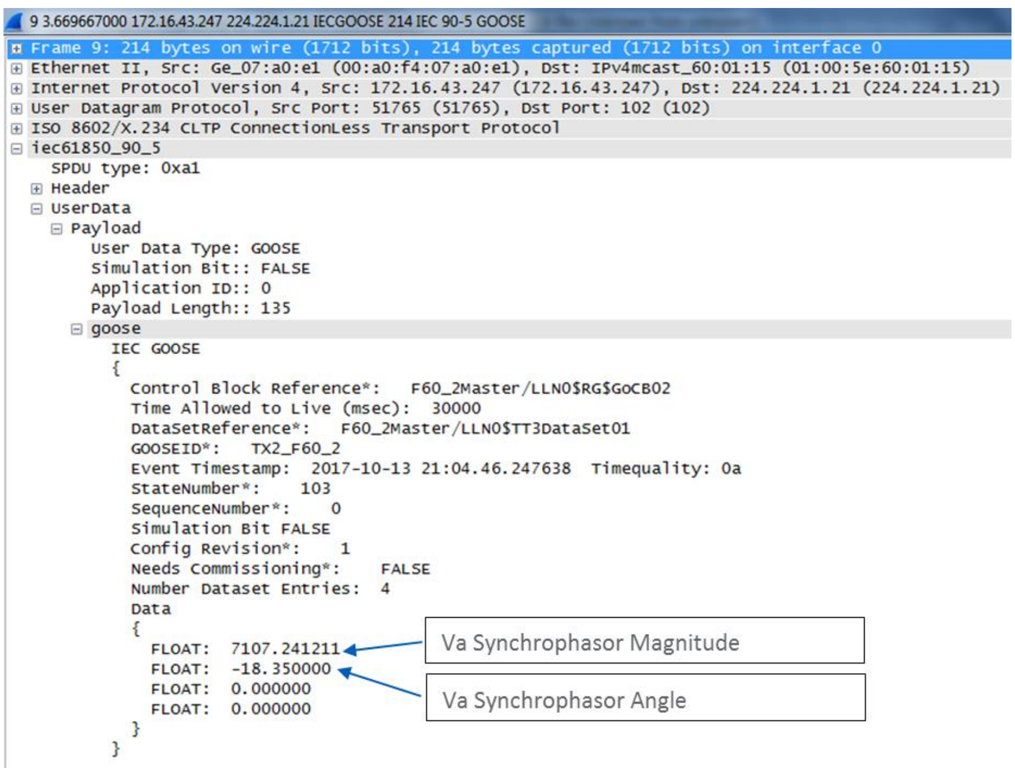


Figure 8b-1

R-GOOSE Capture from Recloser 2

The Tie Breaker Controller, upon receipt of R-GOOSE messages from the Breaker A relay and Recloser B, computed the magnitude and angle difference between these Synchrophasor values. The HMI screen (figure 8a-2 below) shows the values computed next to the Tie breaker. The value set in the RTDS was 45°and the value computed by the controller was 44°.

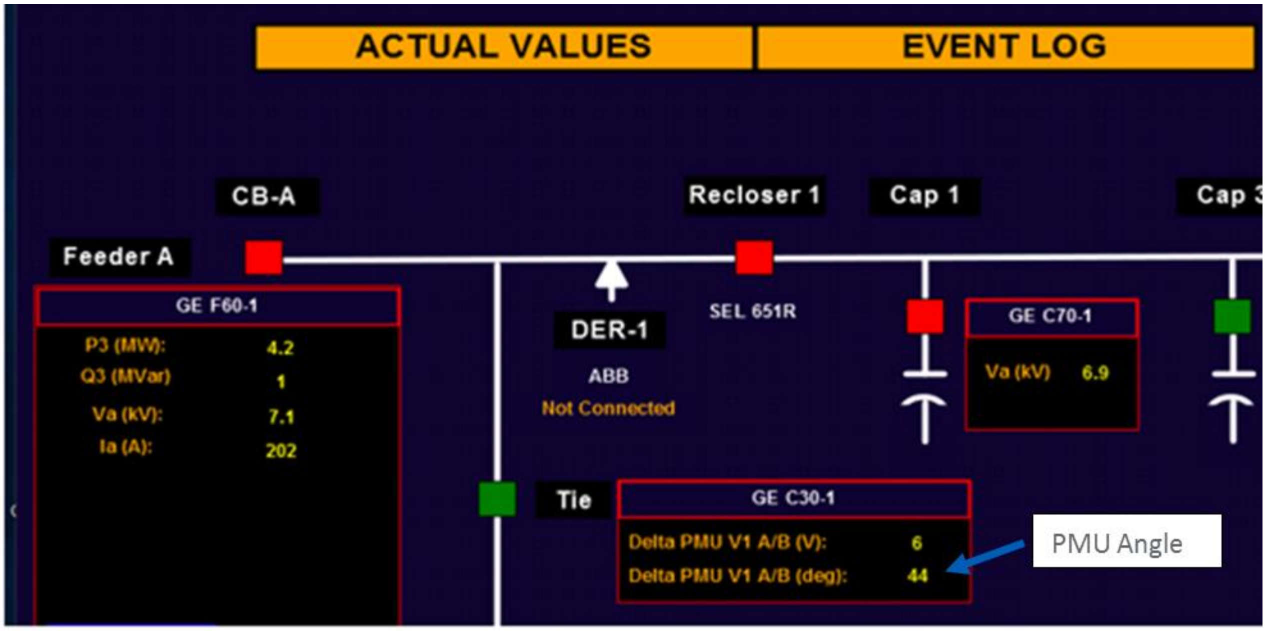


Figure 8b.2

Synchrophasor Angle Difference View in HMI

Communication Observations:

R-GOOSE over Radio Bandwidth Analysis

The R-GOOSE message (above) sending four Floating Point numbers requires a total of 1712 bits. The bandwidth of the radio network is about 500,000 bits/second. Rounding up to 2,000 bits per message, a radio network could potentially transport up to 250 R-GOOSE messages/sec. It should be noted that the transmission of R-GOOSE it typically event-based and uses minimal bandwidth. Use of a 0.1% Deadband will result in a Synchrophasor transmission when the angle changes 0.36° or a magnitude change of 15 volts. Operating in this mode, Synchrophasors between sources will never be more than 0.36°or 15V out of alignment.

Related to Synchrophasors via R-GOOSE/GOOSE, the IEC 61850 standard defines a periodic transport profile – based on the Process Bus profile – for the periodic transmission of Synchrophasors. This IP Address section of the protocol for this profile is identical to that of the R-GOOSE and, as such, implements an IP-Multicast – including a complete security profile.

OpenFMB Gaps:

The implementation of the MQTT OpenFMB protocol in edge devices would have been unable to keep up with the 10 messages per second transmission that was possible with R-GOOSE. Additionally, the MQTT Broker would have introduced additional communication delay. The limitation in the R-GOOSE implementation was the Scan time in the detection of changes in the Synchrophasor values – which could be enhanced.

Recommendations:

The mapping of Synchrophasors into R-GOOSE is a new way to send Synchrophasors. In existing implementations, synchrophasors are continuously streamed – requiring much bandwidth. By using the Deadband transmission mechanism of R-GOOSE, Synchrophasors were only sent when there was a user-defined change in the Synchrophasor value. In the implementation, a deadband of 1% was set – limiting Synchrophasor transmission in steady state conditions. An event on the line – such as a breaker or recloser operation – would trigger Synchrophasor transmission. In as much as R-GOOSE latency was low, transmitted Synchrophasors were self-aligning – meaning that a difference in values could be computed with the understanding that there was only, at most, a 1% difference is transmitted values. SDG&E has demonstrated the use of Synchrophasor differences for the detection of broken wires. It is suggested that SDG&E examine the use of R-GOOSE for Synchrophasor transmission instead of continuous transmission. Additionally, since R-GOOSE is a Pub-Sub protocol, an R-GOOSE message can be sent directly to another PMU where differences in the Synchrophasor values can be computed – simplifying the communication and computation architecture.

16 Test Case 9a – Dynamic Subscription (Documentation Only)

16.1 Test Case Description – UC 9a Dynamic Subscription (Documentation)

UC 9a Dynamic Subscription

Objective:

- Identify the requirement for dynamic subscription for all messaging protocols for incorporation into OpenFMB standards.

Description:

- In the scenario when Feeder A and Feeder B are separated, there is no need to share messages between them. Once the Tie SW is closed, it becomes desirable for the devices on Feeder A to be able to “subscribe” to information from devices on the “extended” line.
- For this purpose, it is to be noted that Dynamic Subscription becomes a need in this Test case.
- Additionally, the definition of the data objects from the newly subscribed devices may be needed – especially if there had been setting changes in any of the newly-subscribed devices.
- Note: Documentation included in Final Report

17 Test Case 10a – End-to-End Security (Documentation Only)

17.1 Test Case Description – UC 10a End-to-End Security (Documentation)

UC 10a End-to-End Security

Objective:

- Identify the requirement for end to end security into OpenFMB standards.

Description:

- When communicating device-to-device in the field, end-to-end secure communications are required.
- End-to-end security should be developed that addresses authentication, authorization, access control, confidentiality, integrity, non-repudiation, availability, and accountability.
- Note: Documentation included in Final Report

18 Test Case 11a – Administration of Devices using OpenFMB

18.1 Test Case Description – UC 11a File transfer

UC 11a File transfer

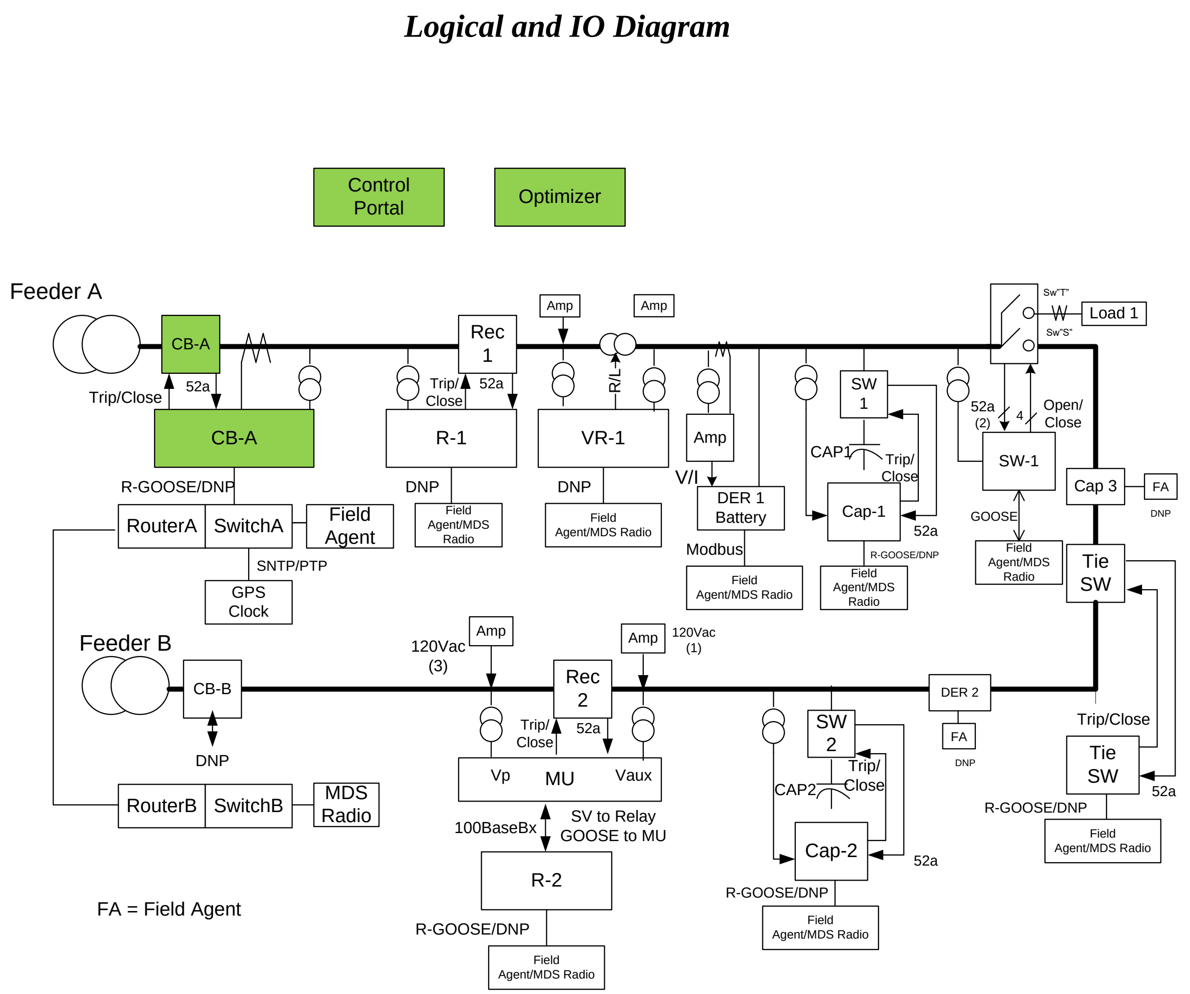
Objective:

- Demonstrate file transfer using OpenFMB

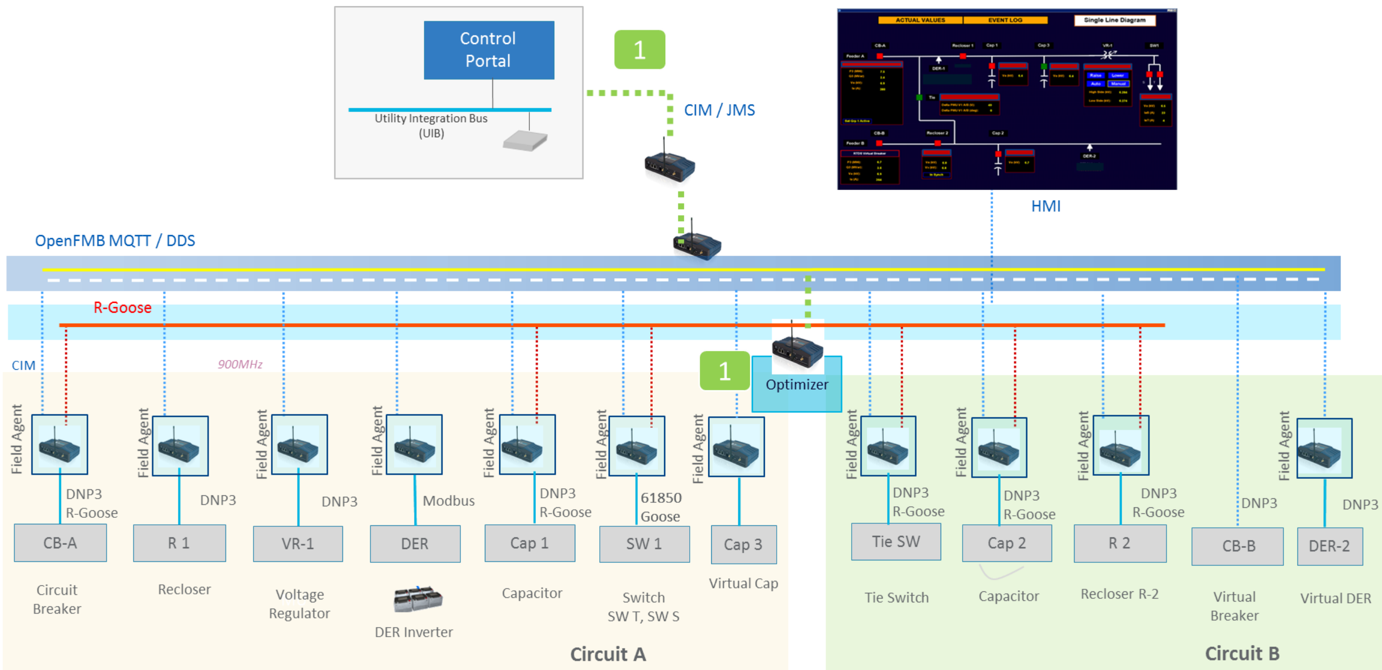
Description:

- To demonstrate the transfer of a settings file, a file will be transferred from the Administration Node to a Field Agent (OpenFMB Adapter). This file will be of a size representative of a settings file - ~10 KB. Settings files may also be unique to each OpenFMB node.

18.2 Test Case Diagram – UC 11a File transfer



18.3 Test Case Diagram – UC 11a File transfer



Data Flow	*Data Flow Summary*	*Sequence*
1.	Control Portal → CB-A Optimizer	Control Portal → CB-A Optimizer

18.4 Test Case Pre-Conditions – UC 11a File transfer

Pre-Conditions	***Description***
1.	2 Circuits (Line A and Line B) with communicable devices on different networks on each line
2.	OpenFMB pre-configured
3.	Multiple field agents connected and communicating via OpenFMB
4.	Optimizer Pre-configured
5.	Control Portal Pre-configured
6.	Network Model with Switchable Devices (2 Circuits)
7.	Tie Switch (TIE SW) is Closed
8.	Cap 1 is Open or Closed
9.	Cap 2 is Open or Closed
10.	R-1 is Closed
11.	VR-1 is Auto
12.	SW-1 is Closed (2 positions)
13.	Control Portal displays measurement values
14.	R-2 is Closed
15.	CB B is Closed
16.	CB A is Closed
17.	CB-A running Optimizer

18.5 Test Case Test Steps – UC 11a File transfer

Steps	*Description*	*Acceptance Criteria*	*Pass / Fail*
#	*Step Description*	*Describe Acceptance Criteria*	*Pass (P) / Fail (F)*
1.	Control Portal → CB-A Optimizer	Control Portal → CB-A Optimizer	P

18.6 Test Case Results – UC 11a File Transfer

Operational:

File Transfer from the Enterprise was performed using the Active MQ profile – a profile that emulates the MQTT profile that is defined as part of OpenFMB. The demonstration transferred the RULES file from the Enterprise Server to the Optimizer (Rules execution engine).

Communication Observations:

The transfer time was excessively long - most likely due to the underlying network saturation caused by the frequent transfer of xml data and R-GOOSE Synchrophasor traffic on the bandwidth-constrained 900HHz Radio network.

OpenFMB Gaps:

A single file transfer mechanism needs to be defined for OpenFMB. Providing multiple options will confuse the market place and make OpenFMB more difficult to implement. In general, since OpenFMB defines multiple protocols, this poses a problem for the industry as a manufacturer will only be able to implement one profile at a time – making inter-operability problematic.

Recommendations:

A single file transfer mechanism for ALL profiled of OpenFMB needs to be chosen. Clearly, any mechanism chosen needs to be securable. It is to be noted that MQTT has been implemented with TLS to achieve secure data transfers in general but even with TLS, a file transfer protocol needs to be chosen.

18.7 Test Case Description – UC 11b Firmware

UC 11b Firmware (Documentation Only)

Objective:

- Document Firmware transfer

Description:

- To demonstrate the transfer of a firmware image, a file will be transferred from the Administration Node to a Field Agent (OpenFMB Adapter). This file will be of a size representative of a firmware image - ~10 MB.
- It should be highlighted in the report that firmware images will need to have various security characteristics that may be unique to firmware such as manufacturer signing. Firmware images may also be unique to each OpenFMB node.
- Note: File size presently limited by file availability
- Note: Documentation included in Final Report

18.8 Test Case Description – UC 11c Provisioning (Documentation Only)

UC 11c Provisioning (Documentation Only)

Objective:

- Document the requirement to provision field devices using OpenFMB

Description:

- To set up an OpenFMB network, the secure provisioning of OpenFMB nodes is critical. Each OpenFMB node will need to have its security credentials verified with the Administration Node. Various settings will also need to be communicated relating to both the node's network and the node's application functionality. Initial subscriptions to other OpenFMB nodes will also need to be created
- Provide example of documentation of provisioning of settings file for a Cap Bank similar to CAP 1 or CAP 2.
- Note: Documentation included in Final Report

19 Test Case 12a – Operational Data File transfer using OpenFMB

19.1 Test Case Description – UC 12a Operational Data File transfer using OpenFMB

UC 12a File transfer (Documentation Only)

Objective:

- Demonstrate file transfer using OpenFMB

Description:

- Demonstrate file transfer from an Administration Node to other nodes through OpenFMB (MQTT) – field agent-to-field agent.

- Currently, OpenFMB does not define file transfer. In the future, OpenFMB may choose to Test another protocol better suited for file transfer (e.g., SFTP) as pub/sub protocols are not typically used for large, point-to-point, file transfers. Further, individual settings and firmware is likely not to be broadcast as security images, configuration, and other aspects are likely to be unique to each node. These are critical points that need to be clearly articulated in the final document.

- Note: Refer to test demonstration Test Case 11a

20 Test Case 13a – OpenFMB using DDS

20.1 Test Case Description – UC 13a OpenFMB using DDS

UC 13a OpenFMB using DDS

Objective:

- Demonstrate OpenFMB using DDS

Description:

- The Tie SW is set as the one of the DDS nodes.
- The Tie SW gets the data (measurement value) from DNP3 adaptor and publishes the data on the DDS virtual FMB
- Another DDS node subscribes to the data.
- Once the data is received, the data is published in the Audit Log

20.2 Test Case Steps – UC 13a OpenFMB using DDS

Steps	***Description***	***Acceptance Criteria***	***Pass / Fail***
#	*Step Description*	*Describe Acceptance Criteria*	*Pass (P) / Fail (F)*
1.	Set Tie SW as one of the DDS nodes	Observe Tie SW as DDS node	P
2.	Tie SW (Node 1) receives data (DNP3 adaptor) and publishes data via DDS OpenFMB	Tie SW data publish to OpenFMB (DDS)	P
3.	Node 2 subscribes to data	Node 2 data is published in the Audit Log	P

20.3 Test Case Results – UC 13a OpenFMB using DDS

Operational:

With a terminal view configuration (figure 13a-1) we were able to watch the data get sent from the DNP3 scanner to the local FMB Broker then verify the expected data was sent by the local FMB broker. The Edge Device represented in the right-hand terminal was configured to listen ONLY DDS and write the received messages to the audit log. This identical xml message in the audit log implies DDS was, in fact, used to transfer the message from one node to another.

Communication Observations:

Although not visible in the Control Portal, the DDS message transfer was successful. The DDS header carried the same XML data description as the MQTT message.

OpenFMB Gaps:

DDS has multiple implementation options for Data Delivery and Quality of Service (QoS). It is noted that one of the DDS QoS options is “continuous” re-transmission of data until a receive receipt is obtained. This is similar to R-GOOSE with the exception that R-GOOSE does not have an explicit acknowledge function but messages can be acknowledged at the application level through implementation of an Acknowledge message – sent by the data receivers.

Recommendations:

In order for DDS to be adopted by the utility industry, a specific profile of a DDS implementation must be developed. The QoS function of Message Repeat is already accepted by the industry and is recommended moving forward. DDS does make use of the Internet Group Management Protocol (IGMP) which allows for Dynamic Subscription to be implemented with DDS.

21 Equipment Analog Status and Control Point Testing

Breaker A (CB-A)	***Control Portal***	***HMI***
Device Attribute	*Pass (P) / Fail (F)*	*Pass (P) / Fail (F)*
Voltage A (kV)	P	P
Volt Angle A (deg)	P	P
Voltage B (kV)	P	P
Volt Angle B (deg)	P	P
Voltage C (kV)	P	P
Volt Angle C (deg)	P	P
Current A (A)	P	P
Current Angle A (deg)	P	P
Current B (A)	P	P
Current Angle B (deg)	P	P
Current C (A)	P	P
Current Angle C (deg)	P	P
Current N (A)	P	P
Current Angle N (deg)	P	P
Active Power (MW)	P	P
Reactive Power (Mvar)	P	P
Apparent Power (MW)	P	P
Power Factor	P	P
Voltage X (kV)	P	P
Volt Angle X (deg)	P	P
Switch Open Status	P	P
Switch Closed Status	P	P
Switch Open Command	P	P
Switch Close Command	P	P
RxGOOSE off-line	P	P
Var Over Limit	P	P
CAP 1 Volt Override	P	P
CAP 2 Volt Override	P	P
Set Grp1 On	P	P

Breaker A (CB-A)	*Control Portal*	*HMI*
Set Grp2 On	P	P
Load Shed On	P	P
Fdr Re-Config Conditions True	P	P
Fdr Re-Config Enabled	P	P

Recloser 1 (R-1)	*Control Portal*	*HMI*
Device Attribute	*Pass (P) / Fail (F)*	*Pass (P) / Fail (F)*
Voltage A (kV)	P	P
Voltage B (kV)	P	P
Voltage C (kV)	P	P
Current A (A)	P	P
Current B (A)	P	P
Current C (A)	P	P
Active Power (MW)	P	P
Reactive Power (Mvar)	P	P
Apparent Power (MW)	P	P
Power Factor	P	P
Switch Open Status	P	P
Switch Closed Status	P	P
Switch Open Command	P	P
Switch Close Command	P	P
Voltage A (kV)	P	P
Voltage B (kV)	P	P

Voltage Regulator (VR-1)	*Control Portal*	*HMI*
Device Attribute	*Pass (P) / Fail (F)*	*Pass (P) / Fail (F)*
Voltage On HighSide (kV)	P	P
Voltage On LowSide (kV)	P	P
Remote Control Mode On	P	P
Local Control Mode On	P	P
Raise Control Command	NA	P
Lower Control Command	NA	P
Auto Control Mode	P	P
Manual Control Mode	P	P

Capacitor 1 (CAP 1)	*Control Portal*	*HMI*
Device Attribute	*Pass (P) / Fail (F)*	*Pass (P) / Fail (F)*
Voltage A (kV)	P	P
Volt Angle A (deg)	P	P
Voltage B (kV)	P	P
Volt Angle B (deg)	P	P
Voltage C (kV)	P	P
Volt Angle C (deg)	P	P
Current A (A)	NA	NA
Current Angle A (deg)	NA	NA
Current B (A)	NA	NA
Current Angle B (deg)	NA	NA
Current C (A)	NA	NA
Current Angle C (deg)	NA	NA
Current N (A)	NA	NA
Current Angle N (deg)	NA	NA
Active Power (MW)	NA	NA
Reactive Power (Mvar)	NA	NA
Apparent Power (MW)	NA	NA

Capacitor 1 (CAP 1)	*Control Portal*	*HMI*
Power Factor	NA	NA
Voltage X (kV)	NA	NA
Volt Angle X (deg)	NA	NA
Switch Open Status	P	P
Switch Closed Status	P	P
Switch Open Command	P	P
Switch Close Command	P	P
RxGOOSE off-line	P	P
Voltage Override Block	P	P

Switch (SW-1)	*Control Portal*	*HMI*
Device Attribute	*Pass (P) / Fail (F)*	*Pass (P) / Fail (F)*
A-Phase Voltage (kV), Z-PT	NA	P
B-Phase Voltage (kV), Z-PT	NA	P
C-Phase Voltage (kV), Z-PT	NA	P
A-Phase Current (A), S Terminal	NA	P
B-Phase Current (A), S Terminal	NA	P
C-Phase Current (A), S Terminal	NA	P
Three-Phase Real Power (MW), Terminal S	NA	P
Three-Phase Reactive Power (Mvar), Terminal S	NA	P
Three-Phase Apparent Power (MVA), Terminal S	NA	P
Three-Phase Displacement Power Factor, Terminal S	NA	P
A-Phase Current (A), T Terminal		P
B-Phase Current (A), T Terminal		P
C-Phase Current (A), T Terminal		P
Three-Phase Real Power (MW), Terminal T		P
Three-Phase Reactive Power (Mvar), Terminal T	NA	P
Three-Phase Apparent Power (MVA), Terminal T	NA	P
Three-Phase Displacement Power Factor, Terminal T	NA	P
Way 1 Closed, Terminal S	NA	P
Way 2 Closed, Terminal T		P

Switch (SW-1)	*Control Portal*	*HMI*
Open Terminal S Command	NA	P
Close, Terminal S Command	NA	P
Open Terminal T Command		P
Close Terminal T Command'		P

Tie Switch (Tie SW)	*Control Portal*	*HMI*
Device Attribute	*Pass (P) / Fail (F)*	*Pass (P) / Fail (F)*
Delta Pmu V1 Mag A/B (V)	P	P
Delta Pmu V1 Ang A/B (deg)	P	P
Delta Pmu I1 Mag A/B (V)	P	P
Delta Pmu I1 Ang A/B (deg)	P	P
Switch Open Status	P	P
Switch Closed Status	P	P
Switch Open Command	P	P
Switch Close Command	P	P
RxGOOSE off-line	P	P

Virtual Capacitor (Cap-3)	*Control Portal*	*HMI*
Device Attribute	*Pass (P) / Fail (F)*	*Pass (P) / Fail (F)*
Voltage A (kV)	P	P
Volt Angle A (deg)	P	P
Voltage B (kV)	P	P
Volt Angle B (deg)	P	P
Voltage C (kV)	P	P
Volt Angle C (deg)	P	P
Current A (A)	NA	NA
Current Angle A (deg)	NA	NA
Current B (A)	NA	NA
Current Angle B (deg)	NA	NA
Current C (A)	NA	NA

Virtual Capacitor (Cap-3)	*Control Portal*	*HMI*
Current Angle C (deg)	NA	NA
Current N (A)	NA	NA
Current Angle N (deg)	NA	NA
Active Power (MW)	NA	NA
Reactive Power (Mvar)	NA	NA
Apparent Power (MW)	NA	NA
Power Factor	NA	NA
Voltage X (kV)	NA	NA
Volt Angle X (deg)	NA	NA
Switch Open Status	P	P
Switch Closed Status	P	P
Switch Open Command		P
Switch Close Command		P

Capacitor 2 (CAP 2)	*Control Portal*	*HMI*
Device Attribute	*Pass (P) / Fail (F)*	*Pass (P) / Fail (F)*
Voltage A (kV)	P	P
Volt Angle A (deg)	P	P
Voltage B (kV)	P	P
Volt Angle B (deg)	P	P
Voltage C (kV)	P	P
Volt Angle C (deg)	P	P
Current A (A)	NA	NA
Current Angle A (deg)	NA	NA
Current B (A)	NA	NA
Current Angle B (deg)	NA	NA
Current C (A)	NA	NA
Current Angle C (deg)	NA	NA
Current N (A)	NA	NA
Current Angle N (deg)	NA	NA
Active Power (MW)	NA	NA
Reactive Power (Mvar)	NA	NA

Capacitor 2 (CAP 2)	*Control Portal*	*HMI*
Apparent Power (MW)	NA	NA
Power Factor	NA	NA
Voltage X (kV)	NA	NA
Volt Angle X (deg)	NA	NA
Switch Open Status	P	P
Switch Closed Status	P	P
Switch Open Command	P	P
Switch Close Command	P	P
RxGOOSE off-line	P	P
Voltage Override Block	P	P

Recloser 2 (R-2)	*Control Portal*	*HMI*
Device Attribute	*Pass (P) / Fail (F)*	*Pass (P) / Fail (F)*
Voltage A (kV)	P	P
Volt Angle A (deg)	P	P
Voltage B (kV)	P	P
Volt Angle B (deg)	P	P
Voltage C (kV)	P	P
Volt Angle C (deg)	P	P
Current A (A)	NA	NA
Current Angle A (deg)	NA	NA
Current B (A)	NA	NA
Current Angle B (deg)	NA	NA
Current C (A)	NA	NA
Current Angle C (deg)	NA	NA
Current N (A)	NA	NA
Current Angle N (deg)	NA	NA
Active Power (MW)	NA	NA
Reactive Power (Mvar)	NA	NA
Apparent Power (MW)	NA	NA
Power Factor	NA	NA
Voltage X (kV)	P	P

Recloser 2 (R-2)	*Control Portal*	*HMI*
Volt Angle X (deg)	P	P
Switch Open Status	P	P
Switch Closed Status	P	P
Switch Open Command	P	P
Switch Close Command	P	P
RxGOOSE off-line	P	P
In Synch	P	P
Fdr Re-Config Conditions True	P	P

Breaker B (CB-B)	*Control Portal*	*HMI*
Device Attribute	*Pass (P) / Fail (F)*	*Pass (P) / Fail (F)*
Voltage A (kV)	P	P
Volt Angle A (deg)	P	P
Voltage B (kV)	P	P
Volt Angle B (deg)	P	P
Voltage C (kV)	P	P
Volt Angle C (deg)	P	P
Current A (A)	P	P
Current Angle A (deg)	P	P
Current B (A)	P	P
Current Angle B (deg)	P	P
Current C (A)	P	P
Current Angle C (deg)	P	P
Current N (A)	NA	NA
Current Angle N (deg)	NA	NA
Active Power (MW)	P	P
Reactive Power (Mvar)	P	P
Apparent Power (MW)	P	P
Power Factor	P	P
Voltage X (kV)	P	P
Volt Angle X (deg)	P	P

Breaker B (CB-B)	*Control Portal*	*HMI*
Switch Open Status	P	P
Switch Closed Status	P	P
Switch Open Command	P	P
Switch Close Command	P	P