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Integrating Distributed Energy Resources into ENMAX's Secondary Network System

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SUMMARY

ENMAX Power Corporation (EPC) owns, operates, and maintains the transmission and distribution systems in and around Calgary (Alberta, Canada) delivering safe and reliable electricity. ENMAX Power serves approximately 510,000 customers across 1,089 square kilometres and has a system peak of 1793MW. This paper outlines the ENMAX Power's initiative to solve the unique technical challenges concerning bi-directional power flow on secondary network systems.

In secondary network systems, customers are fed from two or more paralleled transformers to allow uninterrupted power during contingency. Network systems ensure high reliability to customers but pose a challenge for exporting power as it does not permit bi-directional flow of current through the transformers. Utilities with secondary network systems across North America would have similar challenges with Distributed Energy Resource (DER) interconnections.

The electrical industry is going through a transformation driven by digitization, decentralization, and climate change. Consumer trends, government incentives and reduced technology costs, have led to rapid growth of DERs throughout the distribution systems. ENMAX Power is the first Canadian electric utility to have addressed the issue of permitting bi-directional power flow and integrating DERs onto secondary network systems. In 2018, ENMAX Power secured funding from Natural Resources Canada (NRCAN) and Alberta Innovates (AI) to support this pilot project. EPC partnered with Cadillac Fairview (CF) Chinook Centre to deploy an innovative protection system that enables bi-directional power flow on the secondary network systems.

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This paper summaries the new protection and control (P&C) philosophy for secondary network systems and provides an overview of the engineering design solution, the modifications made to the existing protection scheme and lessons learned from the implementation at the pilot project test site. The DER in the pilot project is a customer owned rooftop solar installation consisting of 1900 PV modules and panels with maximum output of 800kW DC (or 625kW AC). The testing and commissioning for the interconnection of the PV Solar Array was completed, and the pilot site was successfully energized in April 2022.

Aerial View of CF Chinook Center Solar Installation

Supplementary monitoring was added at the pilot site to validate the successful DER export events after implementing the newly developed protection scheme. Two high resolution power quality meters, with remote access capability, were procured and installed at the test site to collect data and monitor DER activity.

The pilot site has continuous monitoring which is planned to remain in place for at least one year. The data collected is being analysed for proof-of-concept to verify successful power export events and identify any reliability, protection, or operational concerns. This project supports Canada's Green Energy initiative and ENMAX Power's vision of grid modernization. After thorough examination of observations from the pilot project, ENMAX Power aims to offer this new engineering solution to other DER customers who may be interested in exporting power onto secondary network systems and maximize their benefits.

ENMAX Power acknowledges that the sponsorship provided by Natural Resources Canada (NRCAN) and Alberta Innovates (AI) was key in the research and development of the innovative engineering design solution developed in this project.

KEYWORDS

Secondary Network System, Grid Network, Spot Network, Network Protector (NWP), Distributed Energy Resource (DER), Programmable Automation Controller (PAC), Protection & Control, IEC 61850, Natural Resources Canada (NRCAN) and Alberta Innovates (AI)

INTRODUCTION

Secondary network systems are specialized low voltage (below 600V) electric distribution systems where electricity is delivered through a mesh of underground cables and network transformer units connected to operate in parallel. Each network is served by minimum two parallel feeders with primary voltages of 5kV-35kV and secondary voltages of 208V – 600V. The secondary network systems are designed to provide high service reliability and do not permit bi-directional current flow through the network transformers due to its unique engineering design.

A network transformer unit is a sealed unit designed to be completely submersible and consists of the following key components:

- High-tension switch - a three position (open-close-ground) gang operated switch which supports primary side isolation.
- Network transformer - a special distribution transformer built for installation in underground or building vaults and available in sizes up to 2500kVA.
- Network protector (NWP) - a self-contained assembly comprising of a circuit breaker, current and voltage transformers, network protector relay and associated circuitry in a submersible enclosure. A NWP automatically connects a network transformer to the secondary bus and can disconnect it depending on the system condition.
- Network protector fuse - provides backup protection to the network protector.

There are two main topologies of secondary network systems: 'Grid Network' and 'Spot Network' systems. A Grid Network System (Figure 1) is an interconnected mesh of secondary cables energized by multiple primary feeders and network transformer units installed in different vaults. The primary feeders of a grid network are fed from a common distribution substation bus (or transformer). Grid network vaults have their secondary buses tied to create a common secondary network bus. The secondary bus voltage level in grid network system is typically 120/208V and can often cover multiple city blocks. A grid network system is also referred to as a 'Street Grid'.

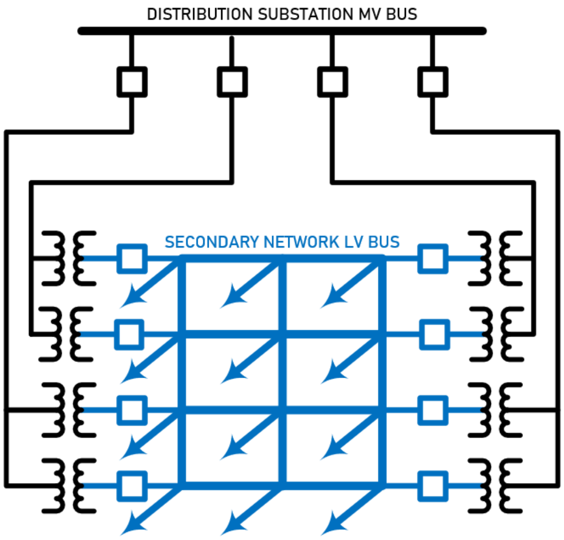

Figure 1: Grid Network or Street Grid System

In a Spot Network System (Figure 2), the secondary terminals of two or more network transformers installed in a vault (single) are connected to create a common bus. There are no additional secondary ties to other vaults. The secondary bus voltage levels of 120/208V, 277/480V or 347/600V are common in spot network systems.

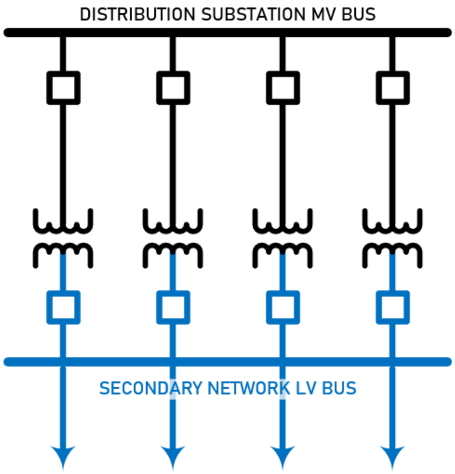

Figure 2: Spot Network System

The Calgary downtown network system originated in 1910. It is one of the largest secondary network systems in North America and the largest in Western Canada. More than 90 per cent of the infrastructure is located underground and is spread over eight square kilometres. Calgary downtown network system boundary and three distribution substations feeding it are shown in Figure 3 below. The downtown network has eight bus zones and more that thousand transformers are part of the network . In addition, there are three spot network systems outside of the Calgary Downtown area.

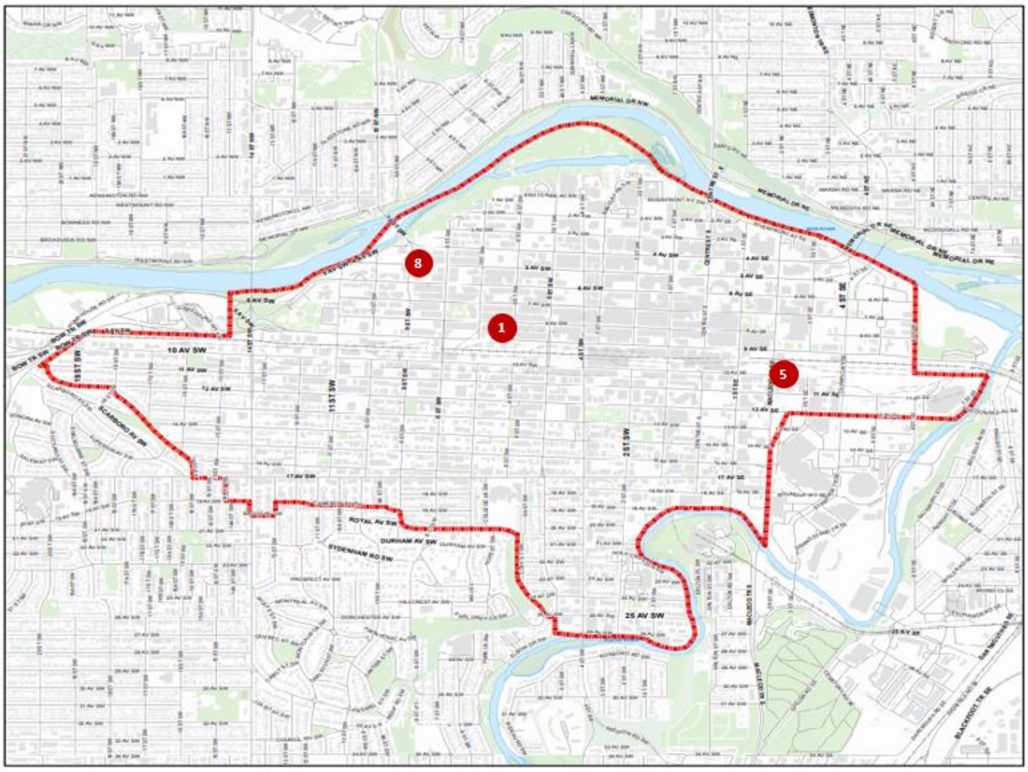

Figure 3: Calgary Downtown Secondary Network System Boundary

ENMAX Power has an ongoing project to install fibre communication into all network vaults for the purpose of monitoring and control. This fibre installation provided an opportunity to use communication aided protection schemes and develop a protection philosophy that will help enable DER power export onto the ENMAX secondary network system.

TECHNICAL BARRIERS TO DER INTERCONNECTION

In typical radial distribution systems, customers can generate electricity, interconnect to the utility and export power back to the grid. However, this is not possible for customers in the secondary network system because they are fed from a complex mesh of transformers with additional limitations imposed by reverse power protection. The higher reliability provided by secondary network system does not inherently allow power export due to its unique engineering design.

Several key criterion and challenges were noted during the project initiation while envisioning an engineering solution to enable DER export onto the secondary network including:

- Secondary network system reliability and safety must not be negatively impacted by the proposed design solution.
- In the new scheme, it is essential to desensitise the reverse protection to permit bi-direction power flow and that may lead to slower fault clearing in certain scenarios.
- A preference to utilise the existing assets and materials where possible to reduce costs.
- The existing protector cabinet has limited space available to add new equipment, thus consideration for a separate cabinet.
- New equipment selection must consider space limitations, discrete input/output requirements, IEC 61850 protocol compliance and the absence of a DC source in the vault.
- Water ingress is a well-known concern for network vaults, so any new equipment design must be submersible.
- The auto reclosing function of the network protector relay will not work when DER is exporting power and might be an operational concern.
- The existing telecommunication network's ring topology design should provide redundancy and reconfigure communication automatically through the other side of ring after loss of single link.
- GOOSE messages and SCADA data will be communicated on the same telecommunication network and network traffic congestion could affect the performance of the DTT scheme.
- Field crews needed to fully understand and accept the proposed solution before it would be implemented.

The engineering team worked carefully towards a solution to ensure the above listed challenges were addressed.

NEW PROTECTION SCHEME - THEORY OF OPERATION

The primary challenge for this project was to find a solution to allow reverse power flow while maintaining system reliability and safety. Most network protector relays from different manufacturers have multiple protection elements available with similar characteristics. The protection elements were studied in detail to understand functionality and evaluate their operation in our application.

Insensitive Reverse Power Protection

In the new protection scheme, P&C engineers utilised one of the available protection elements in the standard network protector relay. In the existing scheme, a 'Sensitive' protection element is set to operate at very low pickup values and does not allow any reverse power to flow. In the new scheme, an 'Insensitive' protection element is enabled which permits a predetermined level of current to flow in the reverse direction and trips if this current is above the pickup threshold. The insensitive element pickup has been set to 100% of full load current of the network transformer at the test site. The insensitive pickup setting is specific to the network vault configuration and will need to be calculated on a case-by-case basis.

Direct Transfer-Trip (DTT) Scheme

A communication assisted protection and control DTT scheme is implemented to permit DERs to export power onto the secondary network system when conditions are acceptable and isolate DERs when they are not. The DTT scheme is designed to operate in parallel with the network protector relay and triggers the same trip coil of the NWP breaker. This scheme complements the reverse power protection and provide faster fault clearing.

For implementing the DTT scheme, programable logic controller (PAC) devices are required at the distribution substation and in each network vault with a DER interconnection. IEC 61850 communication protocol is selected for transfer tripping because it satisfies the important requirements like low latency, high operational reliability (inherent supervision), adaptability (priority tagging) and multi-vendor inter-operability. Figure 4 (below) shows the block diagram for the GOOSE communication. The protocol is ethernet based and provides a framework of exchanging data via publisher/subscriber mechanism.

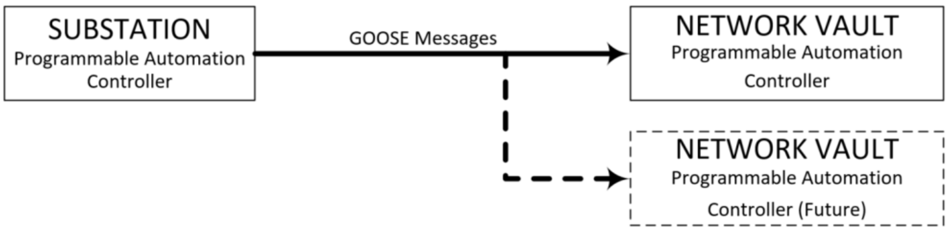

Figure 4: Block diagram of IEC 61850 GOOSE Communication

The substation PAC is setup to monitor the status of substation breakers, associated protection relay trips and executes its encoded logic to publish the GOOSE messages. A DTT message is transmitted when:

- Substation is in an abnormal system configuration (contingency).
- 'Loss of supply' conditions is identified due to protection operation or any other event on the high voltage system.
- Export is disabled manually via local or remote control (Normal state is 'ON').

The network vault PAC is setup to monitor the status of NWP breakers and is subscribed to receive GOOSE messages from the substation PAC. The vault PAC processes the encoded logic and:

- Trips the NWP breakers via hardwired output contacts when the substation breaker of the primary feeder feeding the NWP is opened or tripped.
- Communicates with the DER facility based on the network vault system conditions.

Note: This application is designed to be failsafe; if communication between substation PAC and network vault PAC is lost, all the network protector relays in the vault are reset to provide sensitive protection and toggles back to insensitive protection when communication is restored (achieved via custom DNP logic implemented in network PAC).

<u>DER Communication</u>

The network vault PAC is setup to transmit the following serial communication signals to the DER facility:

1. EXPORT OKAY: The DER is permitted to export power when the network vault is in a normal or N-1 system configuration **and** the feeding substation is in a normal configuration with a healthy communication link available between the substation PAC and network vault PAC.
2. RUNBACK: The DER is expected to runback to parallel non-export mode when network vault is in an N-2 system configuration **and the** feeding substation is in a normal system configuration with a healthy communication link available between the substation PAC and network vault PAC.
3. TRIP: The DER is expected to trip the generation for any of the following conditions -
   - Substation automation controller initiates a DTT for loss of system supply condition.
   - Loss of communication between substation PAC and network vault PAC is detected.
   - Network vault is in emergency state (N-3 contingency i.e., three out of four network transformers are not available).
   - Export is disabled manually via local or remote control (Normal state is 'ON').

Note: The three DER signals are mutually exclusive (only one of the above three binary digital signals is TRUE at any given time). This application is designed to be failsafe; if communication between the network vault PAC and the DER facility is lost, the DER will be tripped.

The DER facility transmits its main breaker status and other telemetry signals (analog and digital) as per ENMAX Power's DER Technical Interconnection Requirements document (https://www.enmax.com/GenerationAndWiresSite/Documents/ENMAX-Power-Dist-Energy-Resource-Technical-Interconnection-Req.pdf). The DNP3 point list is reviewed and finalized for each DER facility SCADA system.

ENGINEERING DESIGN SOLUTION

The Engineering design development phase is the most important time of the project during which many significant features of the design are decided. Members from multiple engineering teams collaborated and worked together during the design development process to create a design that is engineered correctly and has all essential components to fulfil the requirements.

The block diagram of the protection cabinet design is shown in Figure 5. The new equipment selected for the application is compact in size, AC powered and installed in a submersible wall-mount encloser. Submersible smart external cables are included in design for watertight external connections. Local and remote control to enable or disable the export is included in the design for the vault cabinet and at the substation.

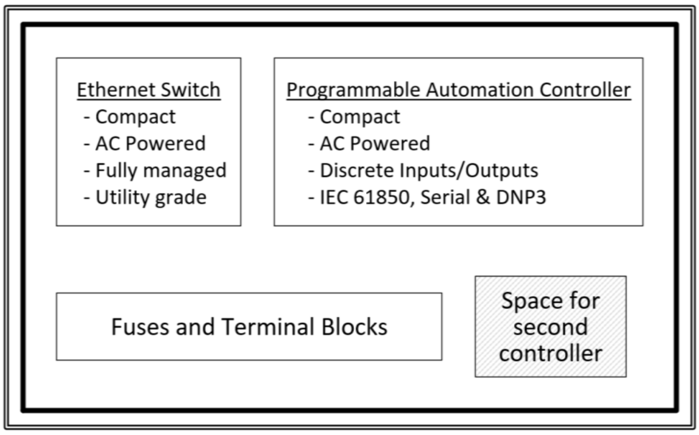

Figure 5: Protection and Control Cabinet Design

The engineering solution developed is for spot network DER interconnection applications. Standardized design will be finalized after reviewing the field markups from the pilot site. The design solution is scalable and is independent of the DER technology type i.e., it would work effectively with inverter-based resources (IBRs), combined heat and power (CHP) or synchronous generation.

TESTING AND COMMISIONNING

Testing and commissioning is done to ensure that the engineering design is safe and meets the design requirements. ENMAX Power hired a third-party contractor to perform offline testing and to validate the new protection and control scheme before any work was carried out at the test site.

Protective relaying and SCADA equipment was provided to mimic a substation feeder with three secondary network vaults with DER interconnected in one of the vaults. Extensive testing was done in the power lab environment to validate the protection elements functionality, SCADA communication and network resiliency.

The third-party contactor provided a detail report with results confirming that the proposed design functioned exactly as expected. They provided recommendations to further improve the application latency performance. With the revised configuration settings of the network vault PAC, the results were faster and provided uniform latency times.

Field testing and commissioning is the last step where all the equipment installed is tested to ensure the performance, reliability, serviceability, and functionality. Field testing also resulted in some minor tweaks and changes to the PAC logic.

During field commissioning, concern wase raised about network vault protection performance during loss of communication between substation PAC and network vault PAC. To resolve this concern, a custom DNP logic was developed to reset the network relays to provide ‘sensitive protection’ when communications are lost and revert to ‘insensitive protection’ when communications are restored. The logic was fully tested and seem to be working as intended.

DATA ANALYSIS & OBSERVATIONS

The pilot site has supplementary monitoring via three phase power quality meters with eight metering channels. These meters are compact, high speed, high resolution, remotely accessible and have automatic reporting capability.

Power Quality meters were added at the pilot site after implementing the newly developed protection scheme to collect data and monitor DER activity. The data collected is being analysed to validate the successful DER export events and identify any reliability, protection, or operational concerns.

The site is fully operational and multiple successful exporting events have been recorded over the summer. At present, the impact of different inverter operation modes on the secondary network system is being studied.

ACCOMPLISHMENTS

The protection scheme developed for this pilot project has been working well. Based on the positive ongoing results of the pilot test site installation, this protection scheme is proving to have a successful implementation and power export has been achieved on a secondary network. The customer is pleased with the installation and have not reported any mis-operations or other operational issues pertaining to the protection scheme.

The design solution is scalable and is independent of the DER technology. With some minor tweaks it could be implemented for the DER with CHP or synchro generation. By leveraging the use of existing network devices and fiber optic telecommunication network in the secondary network systems, the proposed solution is economically viable for the customer.

ENMAX field crews were an integral part of the team as they provided their valued feedback to major design decisions as well as installed and commissioned the protection equipment at the site.

Standard engineering design for spot network installation will be finalized after the review of field markups and would become the prime solution for similar types of DER installations. Next steps are to adapt the concepts developed for this installation and apply them to a grid network system which will then provide the opportunity for other DERs to export power.

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