SMART SWITCHGEAR FOR EXTREME INSTALLATION ENVIRONMENTS

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ABSTRACT

This paper presents the lessons learned and challenges of switchgear developed for modern day power systems, where these network components are required to operate in extreme installation environments. The challenges will be presented from multiple perspectives including the switchgear design and testing, end user requirements, and regulatory compliance. The main conclusion of this paper is that power systems can be accomplished in these extreme installation environments, with careful design choices and testing beyond industry switchgear standards.

INTRODUCTION

The drive for smarter grids creates numerous challenges for utilities and distribution network operators. One of these challenges is adapting and upgrading systems which were not originally designed to achieve the smart grid functions. Another major challenge is overcoming limitations and constraints of existing installations which includes equipment ratings, physical size and dimensions, environmental conditions, and regulatory requirements. Lastly, a major component of the network is the switchgear designed per IEEE C37.60 [1] and IEEE C37.74 [2], which historically was only utilized for basic protection functions and manual network reconfiguration.

This paper will present background on these topics as well as the latest generation of switchgear and network components to meet these requirements.

NETWORK COMPONENT UNDERGROUND INSTALLATION ENVIRONMENTS

One of the most challenging aspects of an underground distribution system is the installation environment. The typical installation styles are fixed onto a concrete pad (or "padmount") or in a below grade electrical "vault." A padmount device typically includes a larger enclosure which will be subjected to an outdoor environment including wind, rain, snow, etc., but the switchgear and controls will generally be protected. A vault installation is a much more severe installation, where the switchgear and controls can be directly submerged in water which can contain salt water, runoff from roads or nearby land.

An example of a vault installation is in shown in Figure 1 and Figure 2. In Figure 1, the vault is flooded where all of the components are completed submerged for an indefinite period of time. Figure 2 shows the same vault with the water pumped out for access by the user.

Figure 1. An electrical vault installation flooded with water

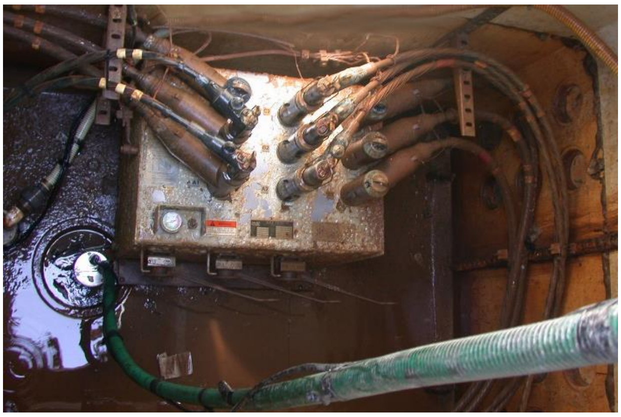

Figure 2. The same electrical fault as Figure 1, with the water pumped out

Typical environmental requirements per IEC 60529 "IP Code" [3] for a padmount switchgear device would be IP55, primarily due to the large enclosure protecting the equipment. For a vault environment, a IP68 rating of 20' of overhead water for 20 days is typical. This rating is extreme but realistic, as some installations are submerged indefinitely.

Vault Installation Water Content

Testing to IP68 ratings is only the beginning in designing next generation switchgear. Due to the contents of the water in the vault, the materials used in the switchgear are critical. Samples from end user installation locations include contents high in corrosive materials such as chloride, as shown in Table 1. Typical contamination can include chloride in the 3000 mg/L levels.

	"Typical" Contamination Levels	
	Fertilizer Contamination	Seawater Contamination
pH	7.2	8.7
Potassium	18.7 mg/L	154 mg/L
Sodium	152 mg/L	2525 mg/L
Chloride	180 mg/L	3000 mg/L
Nitrate	8.1 mg/L	10.7 mg/L
Sulfate	386 mg/L	1179 mg/L

Table 1

To combat corrosion, the grade and surface coatings of materials is critical. Lower grades of stainless steel will have issue withstanding the environment of a submersible vault. An example of this is shown in Figure 3, where this switchgear was installed for approximately 5 years into a vault that was flooded with water continuously. All the components of the switchgear that are exposed to the environment are various grades of stainless steel.

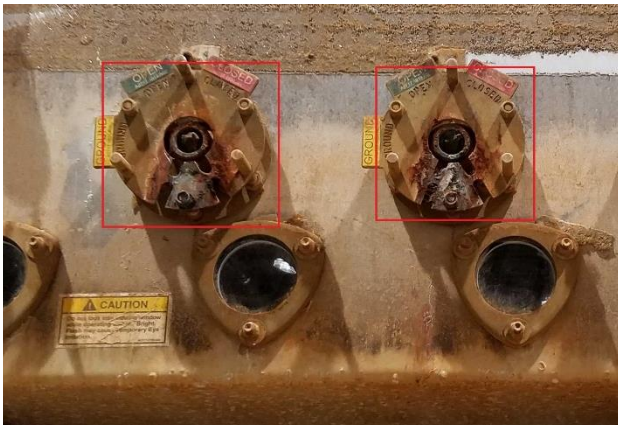

Figure 3. Example of corrosion of stainless steel from a five-year-old device

Size and Configuration Limitations

User safe work practices are the forefront of any design including those for a vault environment. With extreme size and access limitations, equipment must be carefully considered for installation, maintenance, and operation.

These challenges are magnified as equipment standards change over time, while existing infrastructure is already in place. An example of this is shown in Figure 4, where the vault was designed for an older style oil switch. In this instance, the end user worked with multiple switchgear manufacturers to design a replacement to fit in the same form factor, as it was not economical to replace the thousands of existing vaults installed to accommodate for different sized switchgear.

Figure 4. An example of a legacy vault designed for an oil switchgear, adapted for newer

Regulatory Compliance

Another challenge that has a large impact on the distribution system operator is environmental regulatory compliance of the vault water. Regulations for removal of water from vaults are becoming more common. In many cases, this includes a log tracking volume, and identifying the body of water to where the vault contents are discharged.

To comply with these requirements, many utilities now pump these vaults manually and do not allow automatic pumping based on water levels. An example of these requirements is detailed by the California Regional Water Quality Control board [4]. This results in the network components, including switchgear, controls, transformers, etc. to be submerged for long or even indefinite periods of time.

NEXT GENERATION SMART SWITCHGEAR

To address these problems and challenges, G&W Electric developed Smart Switchgear for Extreme Installation Environments for utilities and distribution system operators. Presented in this paper are lessons learned on the challenges of developing these technologies.

Next generation switchgear integrates voltage and current sensors for metering and protection, automation and reconfiguration functions, real time diagnostics, among other features that allow for utilities and distribution system operators to achieve a true smart grid while operating in an extreme installation environment. An example of this next generation smart switchgear is shown in Figure 5.

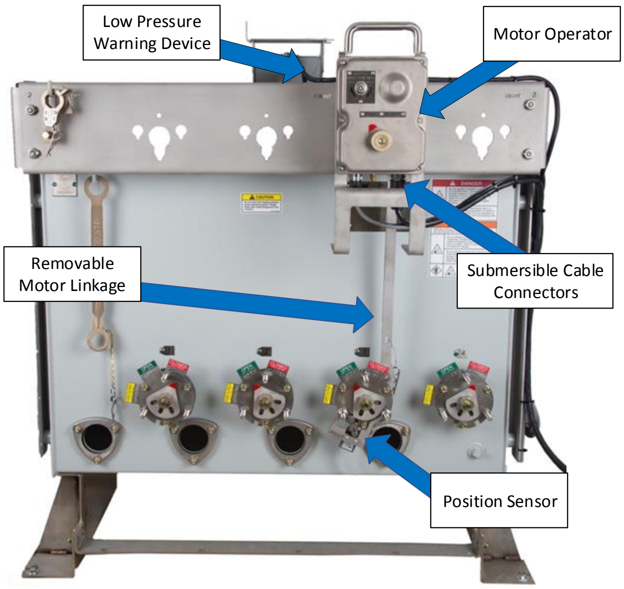

Figure 5. Next Generation Smart Switchgear example

Design Challenges

Remote Motor Operation

The needs for remote operation over SCADA for network reconfiguration is extremely challenging in submersible vault environments. The approach taken for the motor design is similar to switchgear itself, with careful design choices in the materials, sealing methods, and test criteria.

In the example shown in Figure 5, an extra layer of complexity is added, as the motor is designed to be added onto switchgear which has already been installed as a retrofit package. To achieve remote motor operation in this retrofit package, a methodology has been developed to allow for deviations in existing switchgear installation without compromising the integrity the installation. This includes a manual adjustment mechanism of the motor, allowing the lineman to make small adjustments in position to allow for an easier installation. This manual adjustment is critical, as the control for this motor can be in remote locations up to 150' away from the switchgear.

To verify proper seal, a production test is implemented consisting of pressurizing the motor through a valve and submerging it to test for leaks. This test verifies the whole assembly will remained sealed for its life.

Monitoring & Refilling SF6 Gas

To ensure successful and safe remote SCADA operation, an SF6 monitoring system is necessary. As part of the retrofit package in Figure 5, a submersible SF6 density switch was developed. This SF6 density switch includes a hermetic connector to the switchgear as well as a cable to interface with the control.

To combat corrosion, the SF6 density switch is hermetically sealed and made of appropriate grades of materials. As part of the manufacturing process, welding and machining is necessary to hermetically seal the SF6 density switch. These processes can leave residue, which is only apparent after months of continuous submersion and IP68 testing, as shown in Figure 6.

Figure 6. (Left) SF6 Density Switch in new condition. (Right) Sf6 Density Switch with corrosion due to manufacturing processes after months of IP68 testing.

Though the materials are adequate for the design life and corrosion residue has no known impact on the design life, an epoxy coating was added to eliminate the possibility of this corrosion.

Operator Interfaces

Although these network components are installed in extreme installation environments, they are still required to be accessed and operated by linemen. The successful operation and safety of these linemen is of the upmost importance in the design, operation, and utilization of these network components. An example of the operation method is shown in Figure 7, using ropes.

Figure 7. Switchgear Rope Rigging Example

The switchgear mechanism operator interface that the lineman utilizes to operate the switchgear is critical in that it must meet the following requirements, with an example shown in Figure 8.

- Unambiguous labelling of the position and functionality of the switchgear per IEEE C37.100.1 [5]
- Method of allowing only one operation of the switchgear mechanism at a time
- Method to allow installation of a lock to limit operation of the switchgear to certain personnel
- Method to allow linemen to operate the switchgear from a safe distance using ropes, chains, hotsticks, etc.

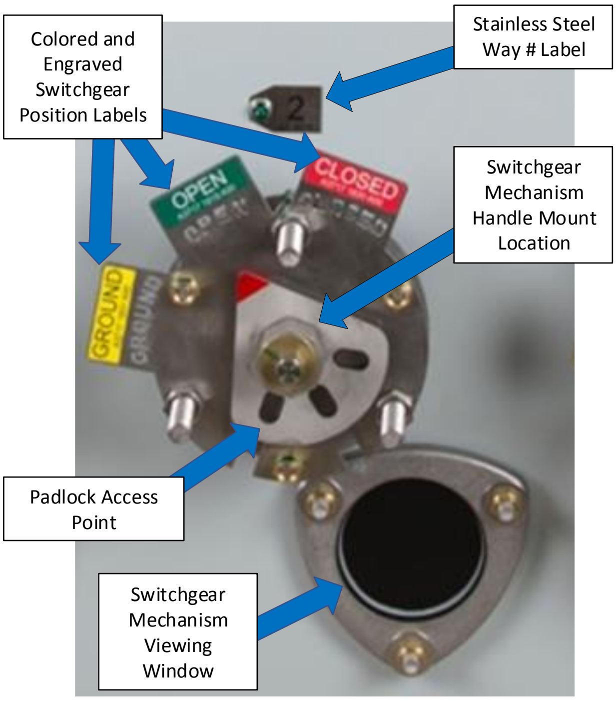

Figure 8. Switchgear Mechanism Operator Interface

Protection, Automation, & Communication Integration

Even in these extreme installation environments, the switchgear is required to function on the network. This functionality includes:

- Overcurrent protection utilizing the internal current transformers
- Under and over voltage protection utilizing the internal low power instrument transformers (LPIT)
- Network reconfiguration utilizing the automation components including motors and magnetic actuators
- Communication of the network status through SCADA

These functions are achieved by using a submersible control such as the one shown in Figure 9. This submersible control includes protective relays, power supplies, radios, modems, interface electronics, etc. to achieve all of these functions.

Figure 9. Typical Submersible Control

The submersible control is sealed in a stainless-steel enclosure to protect the sensitive electronic equipment. To allow for connections to the switchgear, motor, SCADA communication, etc. specialized ports are utilized. These include submersible IP68 rated connectors and cables. G&W has developed special test procedures beyond IP68 requirements to validate these connectors and ports will meet the installation environments. Fig. 10 shows an example of a motor operator being tested for submersion in actual vault water provided by an end user. The submersion test period typically runs 6-12 months of continuous submersion under pressure, with periodic operational checks to ensure the unit is passing.

Figure 10. Showing a motor operator in a submersion test tank for IP68 testing

CONCLUSION

This paper presents an in-depth review of the challenges of extreme installation environments for smart switchgear. The typical environment of the water in an underground electrical vault has been described and analyzed, the challenges of size and configurations have been detailed, and regulatory requirements investigated.

From this work, two main conclusions can be drawn. The first is that extreme care must be taken for the design choices by manufacturers, integrators, and end users to ensure proper operation in these extreme installation environments. Currently there is no industry standard which details all of the requirements or tests for these extreme installation environments and existing test standards could give a false sense of confidence in the performance of design over its intended design life. In many cases, agreements between end users and manufacturers detail testing requirements for specific installations.

The second conclusion is although these installation environments are extreme, there are switchgear solutions to meet these requirements and will function for their design life. This work details some of the development and testing challenges experienced by the authors.

REFERENCES

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[3] IEC 60529, 1989, “Degrees of protection provided by enclosures (IP Code).”

[4] California Regional Water Quality Control Board San Diego Region, Order R9-2015-0117, "Waste Discharge Requirements for the United States Department of the Navy".

[5] IEEE C37.100.1, 2007, “IEEE Standard of Common Requirements for High Voltage Power Switchgear Rated Above 1000 V.”