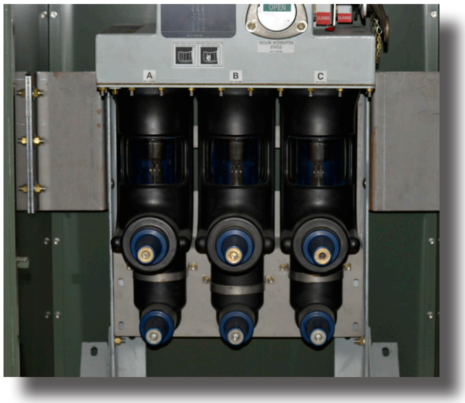
WHITE PAPER

Switchgear Selection Using Life-Cycle Cost Analysis

The 15-25kV pad mounted air insulated distribution switchgear has been the prominent switchgear technology used by many utility companies for decades. This design is widely accepted because it's low cost and it has very little environmental impact when compared to oil and gas insulated switchgear. As the utility industry continues to evolve, distribution planning strategies are looking beyond "low cost" solutions and focusing more attention on reliability, safety, operation and maintenance costs, and automation capabilities.



This paper will present some of the well known drawbacks of traditional air insulated switchgear and introduce dead-front solid dielectric switchgear as an emerging technology that is environmentally friendly and well suited to meet the future needs of the utility industry. A life cycle cost analysis method will be introduced to analyze total cost of ownership of air and solid dielectric switchgear. This paper will also address the critical role that operator safety plays in the switchgear selection process.

Solid Dielectric Switchgear

Solid dielectric switchgear is becoming a widely accepted power system asset for medium voltage distribution systems up to 38kV. This technology incorporates epoxy molding over vacuum bottles and energized components to create individual single-phase dead-front modules. Three-phase solid dielectric switchgear incorporates three of these modules together with single-phase or three-phase mechanisms depending on the application. *Figure 1* shows the internal components of a single solid dielectric module and a three-phase SafeVu switch. Solid dielectric switchgear can be operated by hot-stick, motor, or high-speed magnetic actuator. G&W Electric's solid dielectric switchgear is designed to be 100% dead-front construction. All external components are at zero ground potential and will not flash over if there is condensation or foreign objects introduced into the switchgear cabinet. Optional current transformers and voltage sensors can be molded into the solid dielectric modules sealing them from the effects of environmental contamination and eliminating additional devices externally connected to the switchgear.

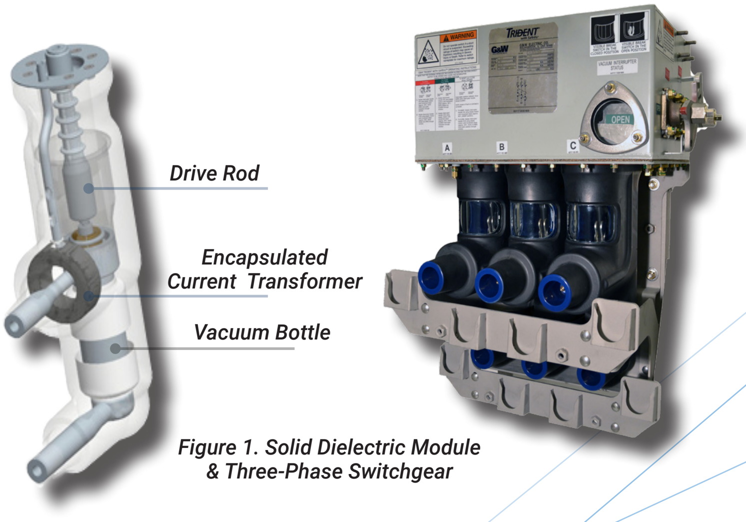


Figure 1. Solid Dielectric Module & Three-Phase Switchgear

G&W Electric
Engineered to order. Built to last.

Three-phase switch modules can be mounted together on a common frame and connected by molded bus components to create a multi-way switchgear line-up as shown in *Figure 2*.

Multi-way configurations provide a high degree of design flexibility and they are ideal for drop-in replacement of legacy air, SF6, and oil insulated switchgear designs. Self-powered vacuum interrupter controls are available with many styles and interfaces to eliminate the need to keep fuses on hand in the event of an over-current condition. The controls harvest the power from current transformers and do not require potential transformers or other means of auxiliary power to operate.

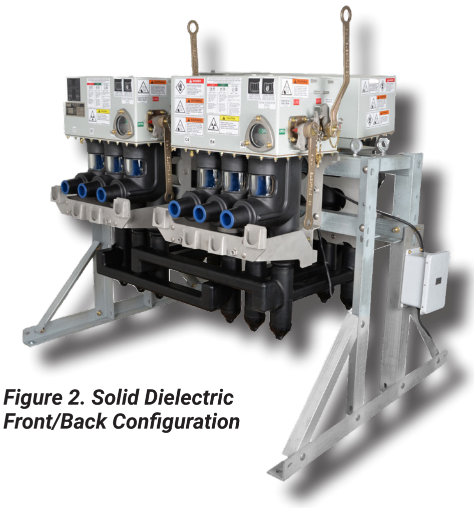


Figure 2. Solid Dielectric Front/Back Configuration

Air Insulated Switchgear

Air insulated switchgear is available in either live-front or dead-front construction. Live-front construction exposes operators to live bus when the switchgear cabinet is opened. Barriers are installed between each phase and cover the live bus components to prevent flash-overs between adjacent phases; but they do not offer operator protection from arc flash, arc blast and resulting concussive forces. Cable connections for each phase are bolted onto a lug landing drilled into the copper bussing. Cable terminations sit low in the switch compartment when compared to dead-front air insulated switchgear where elbow connections are installed closer to the top of the cabinet. Cable splicing or pulling of new cable is required when removing a live-front unit from service and installing a dead-front unit in its place.

Dead-front air insulated switchgear isolates all energized components from operators and uses dead-front elbows and rubber goods for cable connections. This offers a higher degree of protection when compared to air insulated switchgear; however, energized components are still ventilated to the atmosphere and susceptible to excessive wear in harsh high moisture environments.

Live-front and dead-front incoming sources use air insulated load interrupter mechanisms and outgoing taps use power fuses for over-current protection with open/close switches tied to the fuse holders. For purposes of our Life Cycle Cost application, *Figure 3* represents the switchgear configuration under consideration. Power fuse holders and mechanisms allow for change-out of blown fuses while the switchgear is energized; however, switching typically needs to occur with a single smooth operation. To quote a manufacturers operation manual, "The duty-cycle fault-closing capabilities shown for ABC manufacturer represent the fault-closing capabilities of the fuse when the fuse is closed with a purposeful thrust and without hesitation." A safety conscious operator would have to wonder what would happen if there was hesitation while closing a fuse back into service. Our research found many documented occurrences where fuse replacement performed with the switchgear energized led to a catastrophic failure.

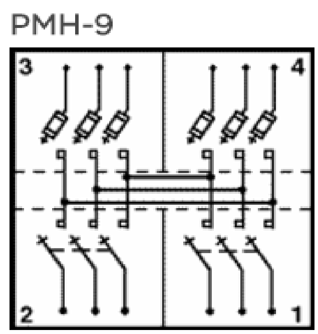


Figure 3 – Air insulated Switchgear 9 Configuration

This is described in Volume 4 of the 2015 SCE General Rate Case, there are documented occurrences in which performing a fuse replacement with the switchgear energized led to a catastrophic failure. Air insulated switchgear relies on traditional power fuses for overcurrent protection. When a fault occurs on a single-phase only the fuse on that phase will operate. This can cause problems for industrial customers that have motors and other apparatus that are sensitive to singe phase conditions. G&W Electric fault interrupting mechanisms are field adjustable for 3-phase or single-phase trip depending on the customers being served by the switchgear.

Whether air insulated switchgear is live-front or dead-front, the energized components within the switchgear are exposed to atmospheric conditions, contaminants, pests, and condensation, all of which are contributing factors to premature switchgear failure.

Life Cycle Cost Model

Life cycle cost (LCC) analysis is a tool used by stakeholders and procurement managers when acquiring a new asset or retro-fitting/refurbishing existing assets. LCC assumes that multiple solutions can meet project requirements and achieve acceptable performance, and that these solutions have differing initial costs, maintenance requirements, operating costs, and useful life. Many different algorithms and data aggregation methods are utilized to aid in creating a reliable LCC analysis that will identify the most cost effective solution available. *Figure 4* illustrates the life cycle cost factors examined in this paper.

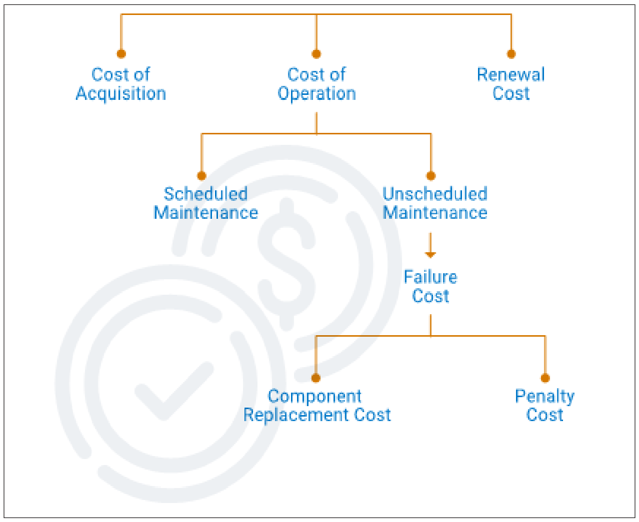


Figure 4 - Life Cycle Cost Considerations

LCC analysis is important because it considers not only first cost of an asset (acquisition and installation cost), but also factors in long term costs tied to maintenance, renewal cost, re-tooling, repair, and failure. Once the LCC model is developed, informed decisions can be made regarding deploying new assets, exploring new switchgear technologies, or refurbishing existing equipment. Evaluating life cycle cost of distribution switchgear will allow for a deeper analysis that may discard solutions with low upfront costs but high operation and renewal costs related to maintenance, repairs, and a higher failure rate due to adverse conditions.

- **Cost of Acquisition**

This is an obvious factor to consider during the purchasing process; however, there are some important points to acknowledge. The cost of acquisition would be the purchase price and the cost associated with installation, training, re-tooling, etc. In other words, this is the cost for deploying the asset. This variable becomes more interesting when you consider a utility or end user purchasing a new switchgear technology for the first time. Costs associated with training, installation, and re-work of existing conditions all need to be considered. In the case of solid dielectric switchgear as a replacement for existing switchgear, it's critical to ensure design flexibility that minimizes any re-work or added install costs that may cause the switchgear solution under consideration to be discarded.

The G&W Electric Trident in-line and front/back configurations were designed with this in mind. The available configurations offer a direct replacement for many of the legacy oil, air and SF6 technologies currently nearing the end of their useful life. Most common switchgear footprints can be maintained with the Trident design and the ease of use of the Trident provides a great high performing switchgear solution that keeps the cost of acquisition at a maintainable level.

- **Cost of operation**

The cost of operation input requires the gathering of data from in service operation and maintenance practices, sensitivity to service interruptions, and the penalties/losses incurred for service interruptions. Well thought out maintenance plans can be compromised due to economic factors, natural disasters, and attrition of the workforce. A "run to fail" maintenance strategy can be a viable one only if direct replacement units are on hand and/or redundancy is present in the system to limit the number of customers affected by equipment failure. When required and suggested maintenance practices are not adhered to the probability of failure increases over the life of the switchgear asset.

From a scheduled maintenance perspective, the Trident product line offers many advantages over traditional air insulated switchgear. First, the Trident switchgear uses environmentally friendly epoxy encapsulation that is maintenance free over the life of the switchgear. This design offers a very high degree of reliability because all electrical components are seal in epoxy. The Trident is also designed as a completely dead-front switchgear assembly. This is a significant improvement over live-front air insulated switchgear that is susceptible to failures by flooding, animal ingress, moisture build-up, and foreign debris.

Automation packages are commercially available for air insulated switchgear however options such as auto-transfer, voltage/current monitoring, bus fault detection, and fault targeting are not available. It is also hardly ideal to automate switchgear when you cannot monitor the condition of your dielectric. In the case of air insulated switchgear automating remote operation without confirmation that the switchgear enclosure is free from debris and moisture can lead to catastrophic failure. Finally, there is no solution available that can automate the outdated power fuses used for overcurrent protection.

G&W Electric offers automation and remote monitoring solutions can reduce maintenance and operation costs, and the penalties incurred by utilities for extended outages. Intelligent relays can monitor contact wear on vacuum bottles and trigger an alarm when a device has reached the end of its duty cycle. Open tie points in distribution systems, open-loop and closed loop automation schemes, and automatic transfer controls are all options to improve reliability and resiliency of the system and the number of customers affected by each outage. G&W Electric's Lazer® automation solutions offer an in depth engineered analysis of a utilities current system and makes recommendations based on the objective of restoring power as quickly as possible to as many customers as possible. Self-healing automation systems can have a significant impact on a utilities overall operating costs by reducing the costs for deploying response crews to locate and repair faulted circuits.

The Trident solid dielectric switchgear product line was designed with automated solutions in mind. Options such as motors, magnetic actuators, auxiliary contacts, and flexibility with many different automation relays allow the end user to deploy switchgear on their network for manual switching and control with the option to easily retro-fit automation capabilities in the future. These automation capabilities will help to drive down operating costs by limiting the need to deploy crews for manual switching and reconfiguration.

- **Renewal Cost**

Renewal cost is defined as the cost associated with parts or components that must be replaced during the life of the switchgear. A good example of a component that would be found under this category would be a fuse. In the event of a fault within the distribution system, power fuses are meant to open and clear a fault to minimize damage to cables and switchgear. Although a fuse may only interrupt current on a single-phase the entire switchgear assemble typically will need to be taken out of service to safely replace an opened or blown fuse. The costs associated with locating and replacing fuses, taking equipment out of service, and keeping fuses in stock will drive up the renewal cost component of switchgear that relies on fuses as a means of protection.

G&W Electric Trident solid dielectric switchgear utilizes resettable vacuum interrupters to protect switchgear cables and other system components in the event of a fault. Once a fault has been cleared, resetting of the fault interrupter is easily accomplished manually with standard tools, motors, or magnetic actuators. This design eliminates the burden and safety hazard of changing fuses while switchgear is energized. When Lazer automated Trident solid dielectric switchgear is deployed on a utilities distribution system, an operator can reset a fault interrupter or reconfigure a circuit without ever leaving their SCADA terminal. This approach eliminates renewal costs and further improves upon overall operator safety.

- **Cost Model**

The information in *Table 1* was found by reviewing public utility and municipality budgeting and construction plans that openly publish costs related to purchase, installation, and repair of distribution switchgear. The remaining information is the result of a sampling of large and small Investor Owned Utilities. The costing assumes a 30-year life for the switchgear asset and two maintenance visits over the life of the equipment for the air insulated switchgear. The air insulated switchgear maintenance visit would include de-energizing the switchgear, adjusting load interrupting mechanisms, checking linkages in fuse holders, inspecting glastic barriers for burning/tracking, checking for signs of pest intrusion and looking for excessive condensation inside the cabinets. The solid dielectric switchgear is treated as a maintenance free design due to the sealed mechanism housing and epoxy encapsulation over all energized components. This design is impervious to any environmental condition and can even be operated in prolonged submersible environments. The construction of the solid dielectric switchgear utilizes 304L stainless steel components to withstand highly corrosive environments and further eliminate the need for inspection and maintenance.

The failure cost was calculated using the U.S. Department of Energy Interruption Cost Estimator tool, http://www.icecalculator.com/. This tool was developed for the Department of Energy by Lawrence Berkeley National Laboratory to identify the estimated cost incurred by a utility for each service interruption. The model uses SAIDI and SAIFI reliability inputs, estimated number of customers on each section of line, and the geographic area where the interruption occurs.

	15kV 4-way pad-mounted life-front Air insulated switchgear	15kV 4-way pad mounted solid dielectric switchgear
Initial Purchase Price	$12,000 -17,000	$35,000 - $45,000
Installation price *	$10,000	$10,000
Maintenance Visit x 2 (every 15 years)	$8,000	---
Renewal Cost (Fuses, barriers, etc)	$2,000	---
Repair due to flash-over (Component replacement cost)	$5,000	---
Cost of service interruption (penalty cost)	$7,500	---
Totals	$44,500 - $49,500	$45,000 – $55,000

**Variable depending on site conditions Note: Pricing varies by manufacturer.*

Table 1- Air and SD Life Cycle Cost Comparison

A quick glance at Table 1 reinforces the need to consider life cycle cost analysis to look past low acquisition cost in favor of a deeper understanding of the total cost of ownership.

- **Safety**

Safety is of paramount importance when considering different switchgear technologies. G&W Electric solid dielectric technology offers a true visible break that is viewable at a safe distance from the switchgear. Air insulating disconnects and visible break contacts in SF6 and oil gear offer a visible open; however, you must be in immediate proximity to the switchgear to confirm open or close position. This requirement will breach the safe approach distance required for arc flash safety. The vacuum interrupter mechanism and visible break mechanisms on the Trident with SafeVu are mechanically interlocked to prevent incorrect operation. The interlock requires the Trident's vacuum bottle to break load or fault current while the visible break is only used for confirmation that the Trident's vacuum bottle is in the open position.

This switchgear does not use a gas or oil dielectric to insulate any of the visible break components. This eliminates the need for monitoring oil/gas levels and eliminates a failure mode due to loss of dielectric.

The Trident with SafeVu shown in *Figure 5* offers the only self contained true visible break using air as the dielectric surrounding the visible break.

Figure 5 – Trident with SafeVu

Conclusion

For many years, air insulated distribution switchgear has been widely accepted for distribution voltages ranging from 15kV to 27kV. Recently utilities have elected to discontinue use of air insulated switchgear in favor of solid dielectric technology. The feedback received points to pest intrusion (snakes and mice) and excessive condensation in the switchgear cabinet as the main reasoning for making the change. There is also a trend to move away from power fuses in favor of self-powered over-current controls and relays. This reduces the burden of asset management teams ensuring several fuses and fuse links are kept on hand and readily available. As one utility customer told us, “We feel that we are moving away from the Ox cart in favor of the automobile.”

Each utility has their own method for evaluating switchgear technologies and making purchasing decisions. G&W Electric continues to invest in engineering, R&D, and quality management programs to bring the best possible switchgear solutions to market. The introduction of the Trident is another milestone in the effort to displace air insulated switchgear as a solution for utility distribution applications. Each product development endeavor at G&W Electric is focused on low cost, high feature content, ease of automation, and high reliability and we will persistently work towards bridging the gap between the acquisition costs of Air and Solid Dielectric switchgear.

References

1. 2015 General Rate Case. Vol. 4, Southern California Edison, 2015.
2. “Interruption Cost Estimate (ICE) Calculator”. U.S. Department of Energy, n.d. Web. http://www.icecalculator.com/