

WHITE PAPER



Medium Voltage On-Site Generation Overview

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INTRODUCTION

It seems that just about everyone is looking for more power. As our dependency on electricity continues to grow, so does the need to design larger back-up generation systems.

The transition from low voltage to medium voltage on-site generation is influenced by a mix of economic and system design considerations including: cabling distance, bus capacity, fault current capacity, switchgear cost, genset cost, and utility interconnection and integration configurations.

Our goal is to help build a common level of understanding around components and system design considerations that readers can build upon when working with medium voltage projects.

WHAT CONSTITUTES MEDIUM VOLTAGE

Depending on your perspective and what standards are being referenced, the definitions of low, medium and high voltage can vary significantly. NEC definitions and perspectives are different from ANSI/IEEE.

- **NEC (systems)**
 - o **0-49 - Low Distribution is covered by 250.20(A)**
 - o **50-1000 - Medium Distribution is covered by 250.20(B)**
 - o **1000-4160 - High Distribution and 4160 & up**
 - o **Transmissions are covered by 250.20(C)**
- **ANSI/IEEE (1kV - 35 kV)**
- **IEEE Std 1623-2004 (1 kV - 35 kV)**
- **NECA/NEMA 600-2003**
 - o **Medium voltage cables rated from 601 volts to 69,000 volts AC**

From a practical standpoint of power distribution, low voltage is considered ≤ 600 volts, placing medium voltage greater than 600 volts. One of the more common electric machine voltages tends to be 4160 volts. This voltage starts becoming very prevalent in industrial environments when motor horsepower starts exceeding five hundred. It is not uncommon to find medium voltage motors ranging from 2400 to 6900 volts. Some of the classical definitions of medium voltage extend to 35 or even 69 kV. This operational range of the category makes sense from a utility / transformer perspective but not necessarily from an onsite generator perspective.

It is common for alternator manufacturers to reference alternators in the 5 kV class (2400, 4160, 6900) as medium voltage and alternators in the 15 kV (12.47, 13.2 and 13.8 kV) class as high voltage – though from the broader sense they both are in the medium voltage category.

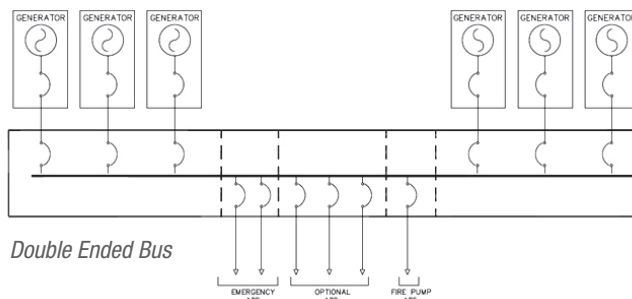
WHEN TO CONSIDER MEDIUM VOLTAGE

There are a number of factors to consider when determining whether to transition from low voltage to medium voltage:

- **Bus capacity**
- **Fault current**
- **Physical location of loads**
- **Cost**
- **Redundancy**

Bus Capacity

Standard bus configurations typically extend to 6,000 amps. Larger busses can be specially engineered though the costs tend to spiral. Fortunately, on-site generation can extend this bus capacity by double ending – bringing generator capacity in from each end and placing the distribution feeder breakers in the middle. This functionally increases this bus limit to 12,000 amps.



Fault Current

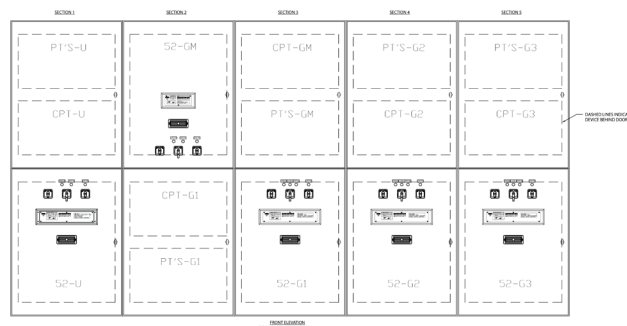
The other limit that tends to appear around the same point is the fault current rating of the paralleling and distribution gear. Once the system fault current exceeds 100 kA, the costs to move to 150 or 200 kA breakers and gear may be economically limiting. Assuming an alternator subtransient reactance of 12%, the 100 kA limit occurs at the same 12,000 amps as the bus limit.

- **65 kA, 100 kA**
- **Rated Amps / $x''d = I_{sc}$**
- **12,000 / .12 = 100,000 amps**

For 480 volt equipment, these limits are converging at 8,000 kW. This tends to be the strong transition point to move to medium voltage or split the low voltage generator bus into two separate systems.

Physical Location

When an application has loads that are physically located far apart, the cost of the low voltage cabling becomes a significant constraint. For



Medium Voltage Switchgear with PT & CPT Compartments
Diagram Complements of Pioneer Power Solutions

campus environment projects with an incoming medium voltage utility service, it is often desirable to consider moving to a medium voltage “power plant” configuration. In this configuration, the entire campus can be backed up with a single medium voltage transfer pair. With this approach, a medium voltage power plant can provide redundant parallel generation capacity to all the step down transformers on the campus. This approach needs to be compared and contrasted with tying in multiple generators around the campus on the low voltage sides of the transformers. Historically, this approach was more common when the low voltage loads didn’t require the reliability of redundant generation.

This approach also provides more choice in which loads would receive back-up power and which would be excluded. With various manufacturers offering integrated paralleling generator options, the low voltage tie-in approach is being considered on more mission critical applications. Pods of low voltage, paralleled generators also offer the advantage of providing protection from a failure of the utility step down transformers.

Costs

Cost is another key factor in the decision to transition to medium voltage. Within the market, transitioning a 480 V, 2 MW generator into a 15 kV unit will likely add \$100,000 to the overall costs, while making the same transition to 4160 V will only add \$40,000.

These added genset costs need to be compared to the cost of installing a pad mounted transformer at each generator. At 4160 V, the medium voltage alternator configuration is fairly common because the costs are similar. At 15 kV, many system designers will look at implementing a step up transformer configuration to achieve some cost savings.

Also when implementing medium voltage solutions, it is not uncommon for utility services to be 23 kV. This voltage will require on-site generators to be transformed -- the highest nominal alternator voltage typically is 13.8 kV. When looking at transformer based solutions, considering 600 V generators may offer some cost savings by reducing ampacity on the low voltage side.

Another area of significant cost is the medium voltage metal clad switchgear (ANSI/IEEE C37.20.2) necessary for paralleling medium voltage generators or creating transfer pairs with the serving utility. This equipment with its associated vacuum breakers, protective relays and instrument transformers typically costs \$50,000 to \$60,000 per section while a typical section only contains a single breaker. When comparing to low voltage solutions, transfer and paralleling equipment is generally twice the cost.

Redundancy

The options mentioned above do provide cost-effective alternatives to medium voltage applications; however, they do not provide redundancy for a failed transformer. As a result, these approaches may not provide the best solution, since many organizations and companies consider the generator system to be mission critical and that factor tends to override the potential cost savings.



Switchgear

MEDIUM VOLTAGE ALTERNATORS

While medium voltage alternators are conceptually the same as low voltage alternators, they differ in the construction relative to the alternator’s armature (main stator). In low voltage alternators, the main stator is typically a random wound machine. This construction uses standard electric machine, insulated copper windings. The construction is called random wound because the wires within the stators slots and on the end turns can randomly lay next to another wire that is many turns further down in the phase coil. This isn’t an issue because the insulation is easily rated for the maximum voltage potential.

In medium voltage alternators, many more coil turns are used in the main stator which keeps increasing the voltage with each turn. The resulting voltage potential would be greater than an individual wire’s insulation could withstand if randomly wound. For this reason, the construction is converted to form coil.



Medium Voltage Form Coil Alternator
Picture Complements of Marathon Electric

The round wire is now replaced with square wire and the wire is precision wrapped to allow the wire to only touch the coil turn above and below it. This controls the voltage potential between turns. The coil is then wrapped with special varnish

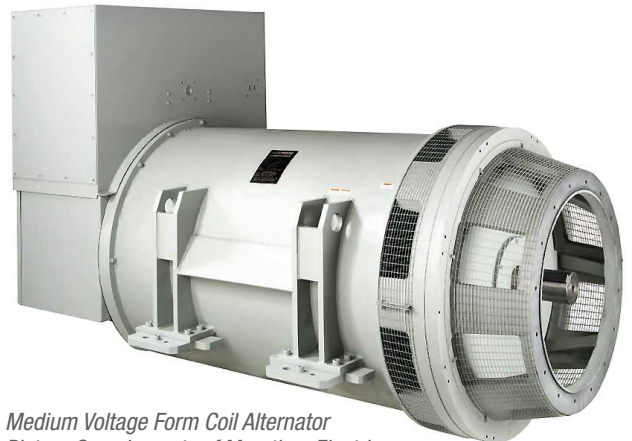
compatible insulating tape to insulate the high potential coil winding from the ground potential of the stator core.

As a rule of thumb, one wrap of tape is needed for each 1000 volts. That is part of the reason why the 15 kV class alternators cost so much more than 5 kV models. The entire stator assembly is varnished using a vacuum pressure impregnation (VPI) process. This process removes the air entrained in the insulating tape and then pressurizes the varnish into the tape. This varnish process is a must for form coil construction but offers few advantages when applied to low voltage random wound alternators that don't utilize insulating tape.

Medium voltage (5 kV and 15 kV class) alternators are typically only available in certain kW ranges. Alternators in the 5 kV class are available as small as 500 kW but are typically implemented ≥ 1000 kW. Alternators in the 15 kV class aren't typically available below 1000 kW with the standard implementation ≥ 2000 kW.

Both classes usually come standard with winding resistive thermal devices (RTDs). RTDs provide a method of monitoring the alternator and protecting it against heating effects due to restricted air flow, phase imbalance or harmonics. However, RTDs operate too slowly to be used to provide short circuit protection.

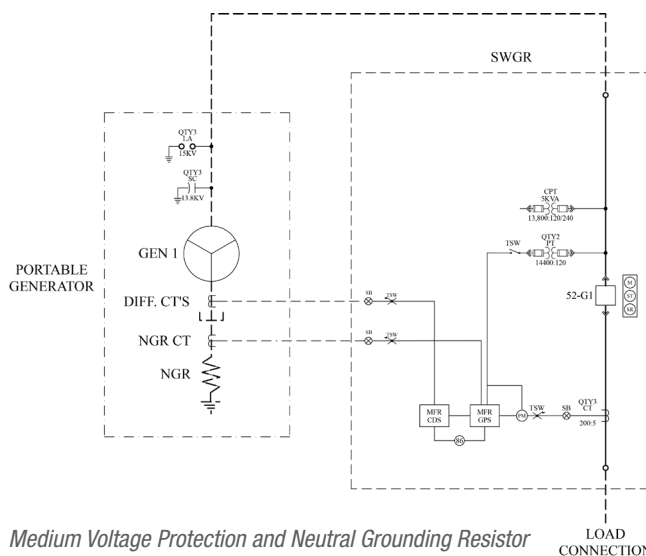
Bearing RTDs are also typically implemented on 15 kV class machines to allow pre-emptive shutdown. Due to the target market and physical size of the insulation, 15 kV alternators are typically implemented in



*Medium Voltage Form Coil Alternator
Picture Complements of Marathon Electric*

large frames (1000 mm stator laminations). This larger frame causes the alternators rotor weight to become too heavy for the engine's rear bearing. As a result, many 15 kV alternators are implemented in a two bearing closed coupled configuration. The second bearing carries the rotor weight and the closed coupling creates easy alignment to the engine flywheel housing.

Medium voltage alternators are configured for bus bar cabling with the switching and protection located within the metal clad switchgear. The genset will include potential transformers (PTs) that step down the main output voltage to typically 120 volts for instrumentation and control. The genset needs this PT input for the voltage regulator control of the alternator voltage and over/under voltage protection within the genset controller.



*Medium Voltage Protection and Neutral Grounding Resistor
Diagram Complements of Pioneer Power Solutions*

PROTECTION SYSTEMS

The generator will also include current transformers (CTs) for monitoring and for overcurrent protection. The CTs are also used to calculate kW, KVAR, and kVA. This information is used for monitoring, protection, and control in the case of on-generator synchronizing and load share functionality.

Current transformers are also often utilized on the neutral side of the alternator phase coils to provide a zone of protection – differential (87) protection – which is implemented by a protective relay located in the switchgear.

This function monitors the current flow between two CTs located at different points within a current path. If the current isn't the same, the path has faulted. This is typically implemented from the high side of the vacuum breaker in the gear to the low side of the alternator resulting in an

extremely high level of protection for all equipment between the two CTs. Medium voltage systems are configured for 3 wire operation (no line to neutral loads). As a result, it is common to use low resistance grounding and then monitor for ground faults with a CT at the resistive bond. This grounding method is typical for 15 kV systems and also used on some 5 kV systems. The grounding resistor is typically sized to limit ground fault current in the 100 to 400 amp range. The resistor is sized by dividing the line to neutral voltage by the desired maximum ground fault current. The protective relaying is commonly set at 10% of the maximum ground fault current. This is done to protect the grounding resistor against the maximum continuous non-tripped ground fault. It is common to set the protective relaying to trip in 10 to 30 seconds.

For 5 kV systems, it is possible to use high resistance grounding when the ground fault current is limited to 8 amps. Above this level it is likely that the fault will escalate into a line to line fault. Systems operating in the 15 kV class typically have considerably higher capacitive charging currents which cause the ground fault currents to easily exceed the 8 amps. For this reason, high resistance grounding is not recommended.

Protective relaying is a significant part of medium voltage systems. Since the vacuum breakers don't utilize integrated over-current trip units, over-current protection is implemented via multi-function protective relay. Given the capabilities of today's multi-function protective relays, it only makes sense to incorporate various functions: differential (87), synch check (25), overcurrent (50/51), over/under voltage (27 /47), over/under frequency 81OU, and ground fault (51N). For applications that utilize a low voltage generator coupled to a step-up transformer, it may be desirable to incorporate transformer differential protection (87T) to protect the entire zone between the high side of the vacuum breaker to the low side of the low voltage generator. This function tends to be fairly specialized and may require an additional protective relay. For detailed design information on grounding and protection, consult the IEEE color book series.

All medium voltage systems require medium voltage metal clad switchgear (ANSI/IEEE C37.20.2) to tie everything together. A typical medium voltage metal clad switchgear lineup will utilize medium voltage vacuum breakers along with the associated protective relaying. It will contain potential transformers (PTs) for stepping down the medium voltage to typically 120 VAC for monitoring and protection. It will also typically contain control power transforms (CPTs) for powering the recharging motor within the vacuum breakers. Together the PTs and CPTs consume the entire upper section above the vacuum breaker.

One strategy to compress the switchgear line-up and reduce cost is to switch the generators breakers to DC close and recharge functionality and use the PTs located on the generators for sensing. This will free up the upper section for another generator breaker. This approach functionally combines two side by side sections into a single dual breaker stacked configuration.

Finally, it is fairly common for metal clad switchgear line-ups to incorporate lightning arrestors and surge capacitors for large generator systems, especially when incorporating 15 kV alternators. The use of these items on the utility source depends on the system topology.

LIGHTNING/SURGE ARRESTORS AND SURGE CAPACITORS

Lightning/surge arrestors limit the severity of a voltage surge to prevent damage of insulation of MV motors, generators and transformers. In its simplest form, it could be a spark gap. A typical surge arrestor features silicon carbide (SiC) discs in series with a small spark gap. When the voltage becomes too high, the spark gap will flash over and the SiC discs will conduct.

The best protection solution is to use surge arresters together with the surge capacitors. Surge capacitors pick-up where lightning arrestors leave off and manage daily surges and transients. They are always connected to the system and limit the rate the voltage and rise to a few amps. They are typically paired with surge arrestors.

CABLING

Medium voltage cable is specialized as the insulation system must maintain its dielectric strength and provide multiple layers of protection. This cabling also uses stress cones which:

- **Transitions voltage potential from wire to insulation**
- **Keeps the insulation from breaking down**

LOW VOLTAGE / MEDIUM VOLTAGE COMBO APPLICATIONS

To help reduce costs, some designs might benefit from a combination low voltage / high voltage strategy. Instead of using medium voltage alternators and paralleling with medium voltage gear, it may be possible to configure a system in which the paralleling occurs on the low voltage side of step-up transformers. This configuration could be implemented with single or multiple transformer configurations.

An effective alternative choice for a medium voltage application below 2 MW is to implement on-generator low voltage paralleling functionality terminating at the low voltage side of a step-up transformer.

For medium voltage applications below 6-8 MW, using multiple step-up transformers with the medium voltage sides terminated together at the gear also creates an effective alternative. In this second configuration, the generators see gen-bus voltage on the low voltage side of the transformer allowing for on-generator low voltage paralleling.

SAFETY REMINDER

Be sure any technician that works on a medium voltage system is qualified to do so. Accessing the medium voltage bus can be dangerous and thus requires very specialized equipment and knowledge. While there is always tremendous pressure to complete projects within tight timeframes, it's far more important to be sure everyone is safe.

SUMMARY

Medium voltage applications can be found in data centers, pulp and paper, plastics and petrochemical industries, heavy manufacturing, and campus environments where loads are physically located far apart. Medium voltage often provides an excellent alternative to overcome low voltage constraints such as cabling costs, fault current and bus ampacity limitations.

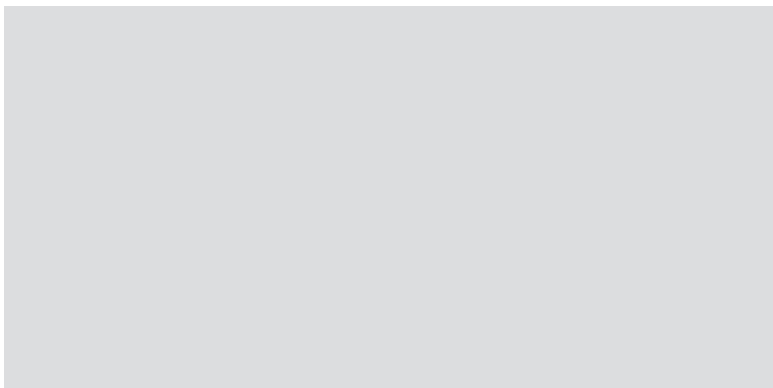
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This information is provided as a service and does not constitute recommendations regarding products for specific applications and should not be relied on as such.

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