Good morning.

My name is Larry Gardner. I am product manager for HVAC drives at Yaskawa America and I work out of our facility in Oak Creek, Wisconsin.

I have some information to share with you regarding variable frequency drives and how, when properly specified and applied, they can help assure occupant safety during fire events.

I expect this presentation will contain some things that some of you already know, so please bear with me on that. But I'm hopeful that all of you will gain at least some information that will help keep the people in your buildings safe.

What to Expect

- Background
- Variable frequency drive (VFD) basics
- Safety concerns
- VFD's role in occupant safety
- VFD emergency modes
- Recommendations for specifications

2018 AHR EXPO CHICAGO JAN 22-24 YASKAWA 2

I plan to spend the next 20 minutes or so speaking about variable frequency drives and how their functions relate to occupant safety in commercial buildings.

First, we'll narrow down the topic, then explore some details, including some basics on how a VFD works, and then end with a small, but important set of recommendations for what is most important for VFD operations in fire events.

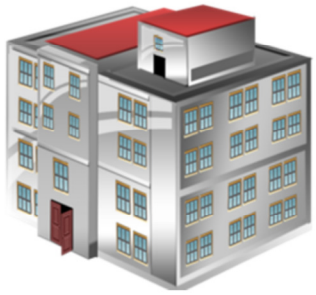
But before we get started, it's important to be clear on a few things that this presentation is not.

I'm not a building design expert, I'm not a trained firefighter, nor am I an authority on building codes or fire codes. And while this presentation concerns variable frequency drives running fans, keep in mind that this is only a part of an overall building management system that must be carefully specified and designed by a qualified building design engineer.

I do, though, have experience in working with major city fire departments to understand their requirements for VFDs controlling fans in fire events. My intent is to share with you some of that experience so that you can obtain the best VFD performance when occupant safety is at stake in emergency situations.

Building Health, Safety, and Welfare

- Eliminate or reduce hazards
- Prevent occupational injuries and illnesses
- Prevent falls from heights
- Prevent slips, trips, and falls
- Perform proper building operations and maintenance
- Ensure electrical safety
- Eliminate exposure to hazardous materials ← HVAC
- Provide good indoor air quality and adequate ventilation ←



2018 AHR EXPO CHICAGO JAN 22-24 YASKAWA 4

Now to narrow down the topic, Building Health, Safety, and Welfare has many areas. It includes things like slips, trips, falls, and building maintenance. Of that list, we're going to focus on two that have to do with HVAC.

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In this case, the hazardous materials we want to eliminate are smoke and harmful combustion gases. And as those are expelled, we want to bring fresh air in – so people can breathe safely while they exit the building and fire crews can safely attack the fire.

Good Indoor Air Quality

- Specify green products
- Proper location of outside air intakes
- Ensure the integrity of the building envelope
- Prevent return air contamination
- Air barriers between thermally different spaces
- Remove potential contaminants from the breathing zone

2018 AHR EXPO CHICAGO JAN 22-24 YASKAWA 5

And as you know, HVAC is all about indoor air quality, which involves several areas. While some air quality issues are annoying and some can sicken, there are some contaminants can be deadly.

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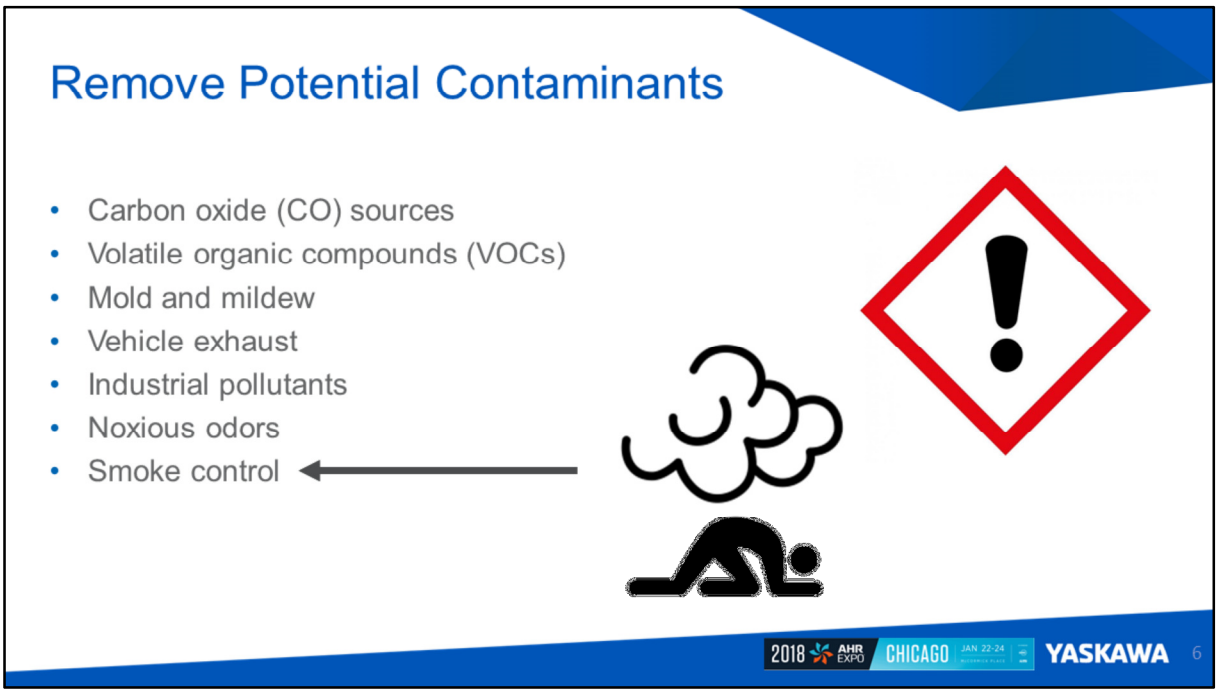
We're going to focus on those contaminants that come from fire.



On the long list of potential contaminants the HVAC designers have to worry about, smoke is one that can kill very, very quickly.

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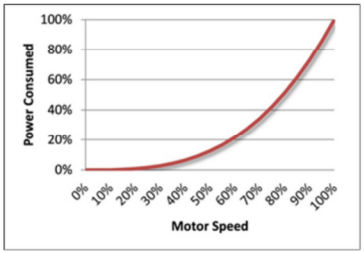
So we're going to focus on the immediate danger of smoke.

Reasons to Use VFDs

- Energy efficiency
  - Power consumed varies with the *cube* of the speed
- Mechanical life
  - Ramp up to speed, ramp to stop
- Controls to match the job
  - PI controls, real-time clock, many others
- Connectivity
  - BACnet, Metasys, Apogee, Modbus, others



ASHRAE BACnet
METASYS APOGEE
Modbus

2018 AHR EXPO CHICAGO JAN 22-24 YASKAWA 7

Before we get into smoke control, let's review why VFDs are used for fans in HVAC applications and then, how they work.

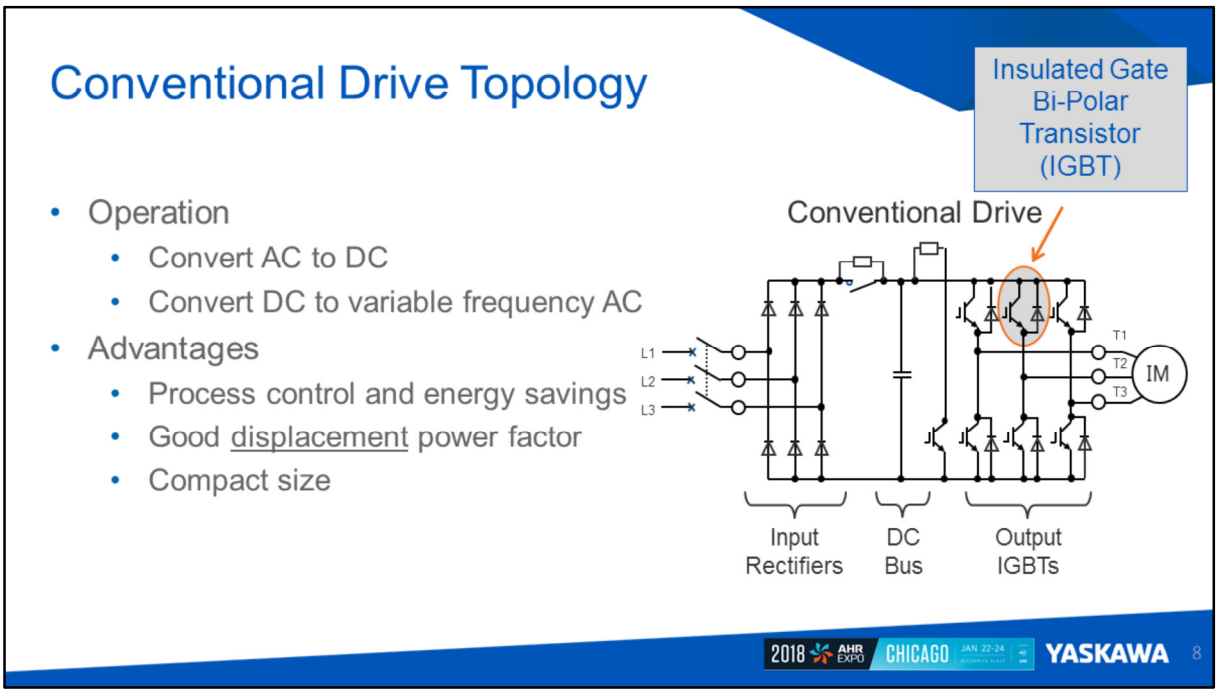
For centrifugal loads, such as fans and pumps, power consumed varies with the cube of the speed.

This means that when the system demand calls for just 80% of full speed, you're only drawing half the power (and half the power bill). At 50% speed, the power is only one-eighth of that at full speed.

VFDs also have the ability to start gently and stop gently, which is obviously much easier on all the system's mechanical parts.

And most HVAC-specific VFDs have BACnet and other building automation protocols built-in.

So in sum, VFDs save money.



Now a quick review on how VFDs work. Conventional VFDs – and I use the term "conventional" here to distinguish them from a newer and different design – are all of the same basic structure.

They use input rectifiers to convert incoming three-phase AC power to DC, and store that DC power in capacitors, referred to as a DC bus.

The business end of the drive then uses high-speed switches to turn on and off to send pulses of voltage to the motor.

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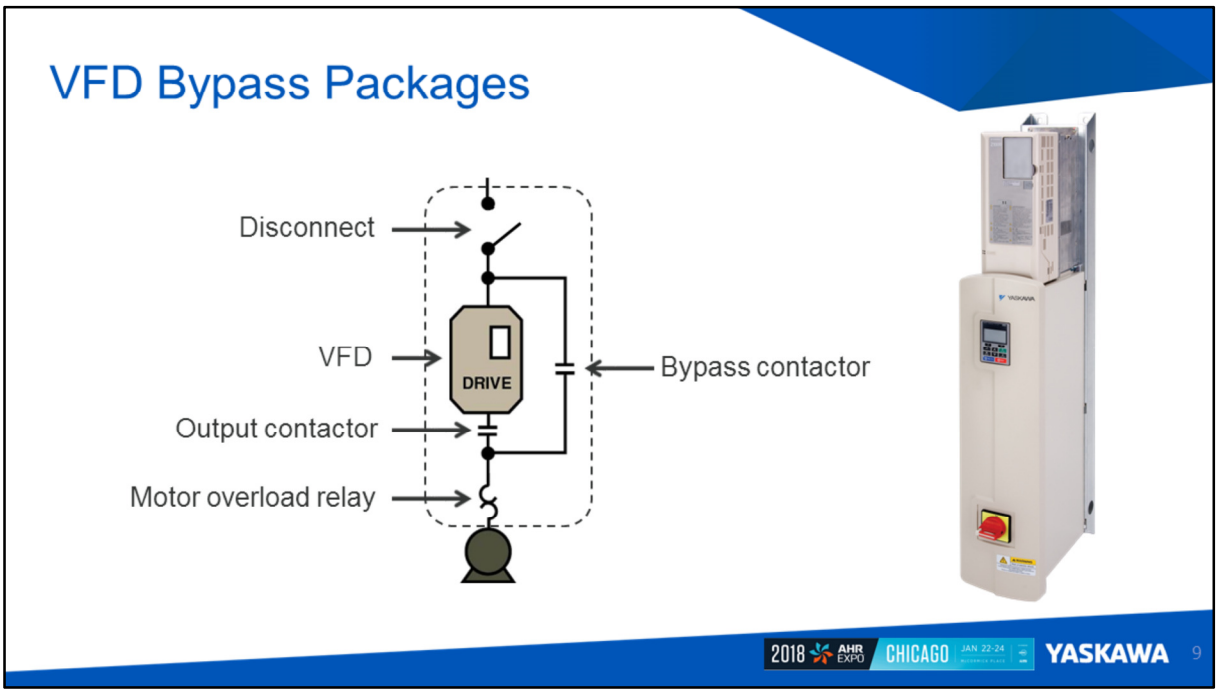
These switches, called Insulated Gate Bi-Polar Transistors, or IGBTs, turn on and off in a sequence that the motor interprets as a sine wave. By varying the frequency of the pulses, the VFD can vary the speed of the motor.



As we've discussed, to run a fan at variable speed, you can use a VFD to vary the speed of the motor.

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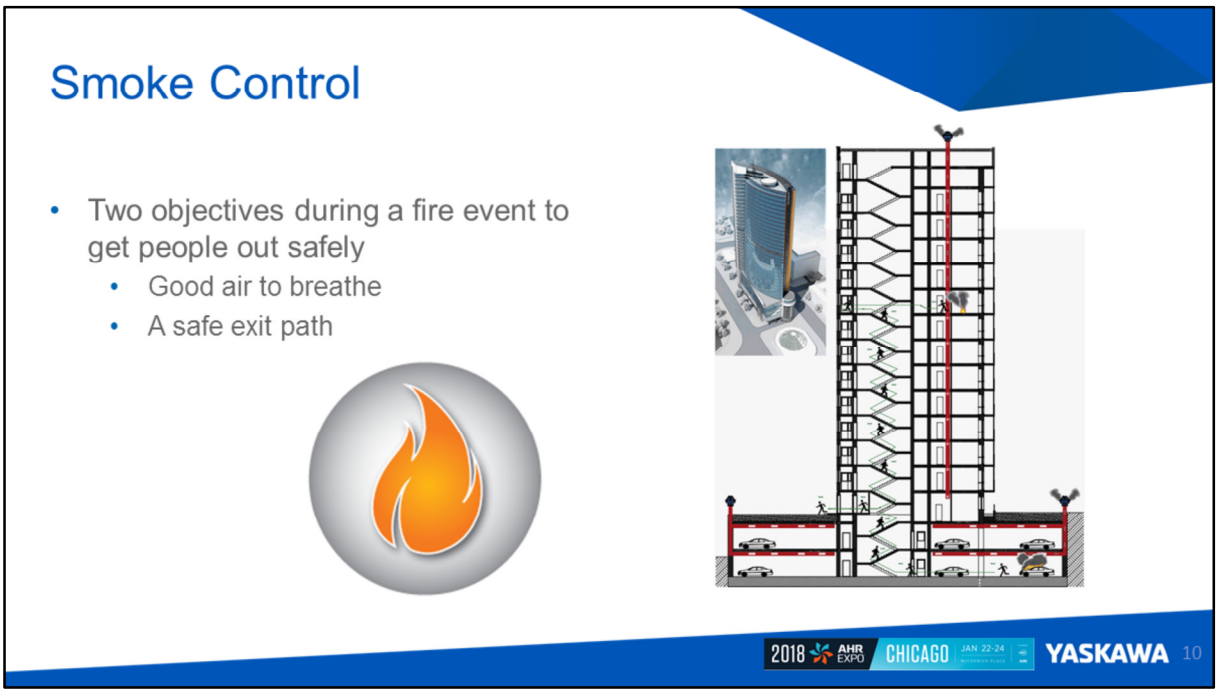
A variation of the VFD is the VFD bypass package. The bypass package, usually referred to simply as "bypass," contains the VFD, plus contactors and logic to enable the motor to be driven either by the VFD or across-the-line. As one would expect, the bypass package is considerably more expensive than the VFD-only, due to the additional components and wiring included.

As we get into VFD control of pressure during fire events, you'll find out how bypasses are selected for some smoke control situations and why they are not for others.



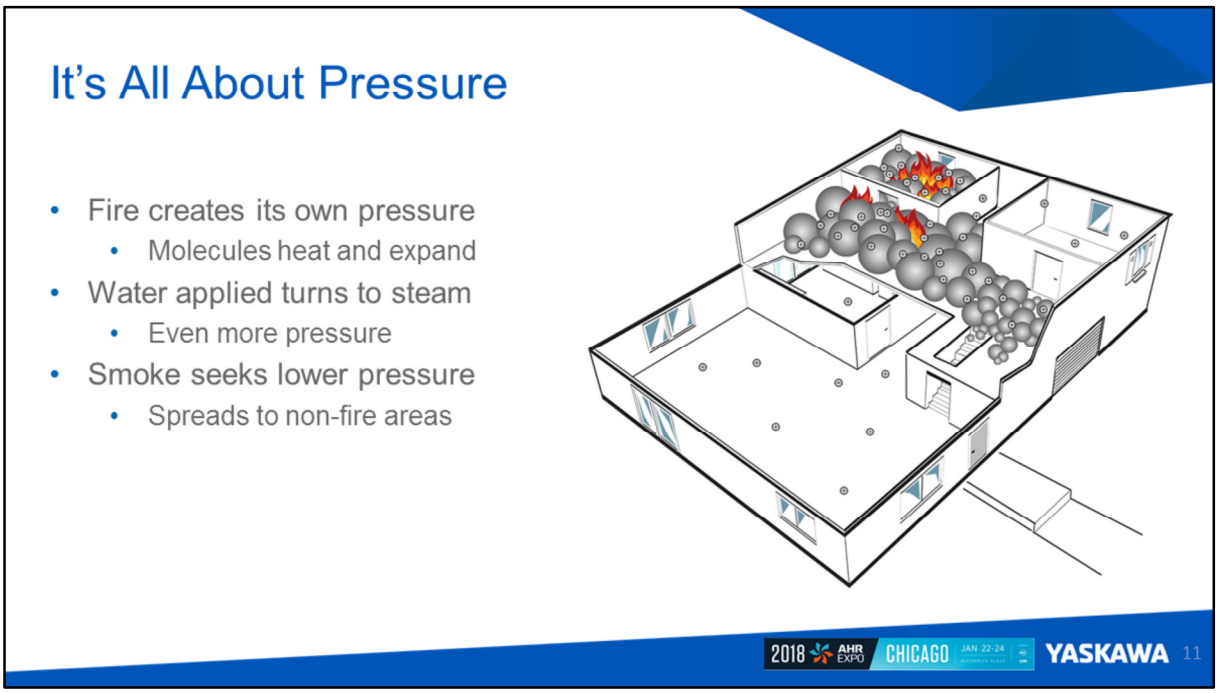
Now that the stage is set, let's talk about smoke control. During a fire event, the primary objective for HVAC is to get people out of the building safely, which, although there are myriad strategies, national codes, and local codes to sort out, it really boils down to assuring building occupants of two things: Good air to breathe and a safe path to exit the building.

Over the years, the application of VFDs used in smoke control has evolved from simple drives moving air. Here, drives operating in their normal modes were subject to being shut down when any of the many self-protective features built into the drive halted their operation.

So, the drives were given special means of operation where they would ignore self-protection faults and "run to destruction," that is, ignore the faults that might cause harm to the VFD, because people safety is more important than machine safety.

The next step in the evolution of drives in fire events is what we'll be discussing here: special modes for the three main tasks to protect occupants and mitigate the effects of fire:

1. Keep smoke from infiltrating safe areas
2. Exhaust products of combustion, and
3. Compartmentalize and control the incident to get the building and occupants back in service much more quickly



In the process of fire, fuel is combined with oxygen to produce light, heat and smoke. In a building fire, this usually mean solid objects are being converted to gas, so what was a relatively small volume is now many, many times its original size as molecules heat and expand. So in that process, fire creates its own pressure within a structure. Added to that, is the pressure from the steam that results from the water that responders apply to suppress the fire.

Undeterred, this pressure causes the smoke and gases to seek areas of lower pressure, and since commercial buildings rarely have wide openings to the outside, that means the smoke and gases will travel through any internal openings to all other parts of the building.

So VFDs are an important means to control smoke by controlling pressure.

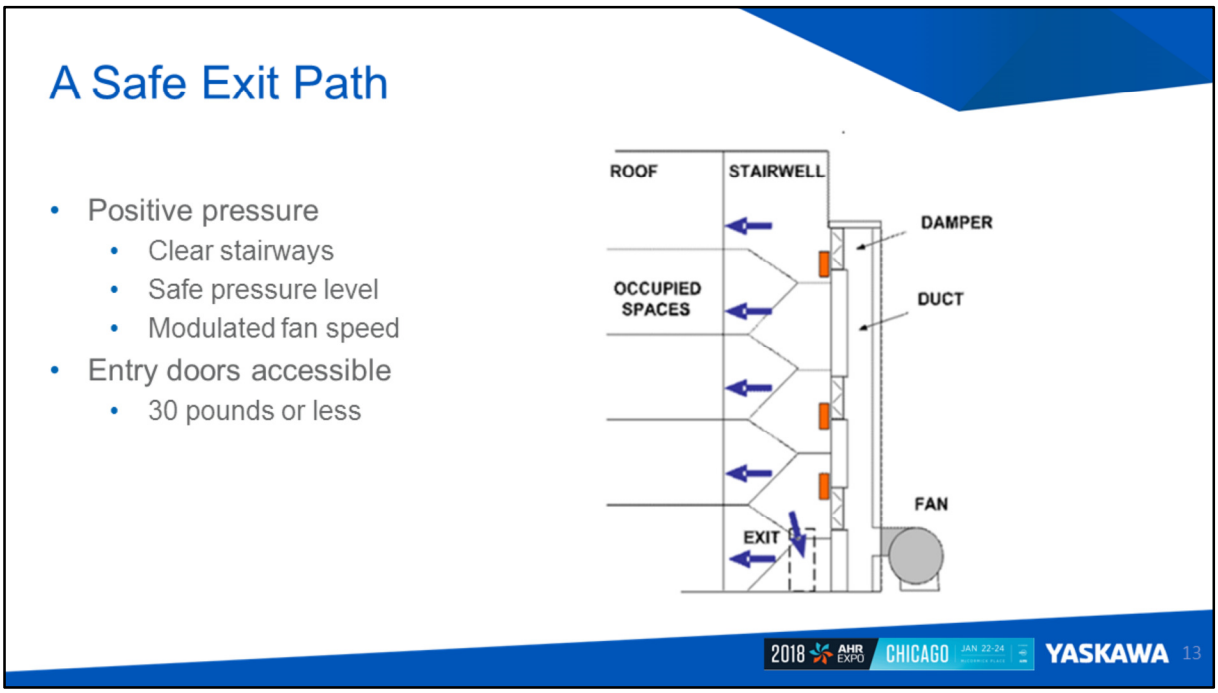
Different brands of VFDs have different modes for dealing with pressure during fire events. The names given for these modes include Emergency Override, Firemen's Override, Smoke Purge, and others, which differ in their capabilities for controlling speed and reacting to faults. However, what they have in common is the ability drive fans to raise or lower pressure to help insure occupant safety.

For purposes of explanation today, we'll use these two terms to distinguish between the use of positive and negative pressure.

In Emergency Override mode, positive pressure prevents smoke infiltration by driving fans to raise the pressure in selected areas higher than that in the area of the smoke origin.

In Smoke Purge mode, VFD-driven fans are used to exhaust smoke from the fire origin to create a negative pressure to both lower the fire's pressure and pull in clean air.

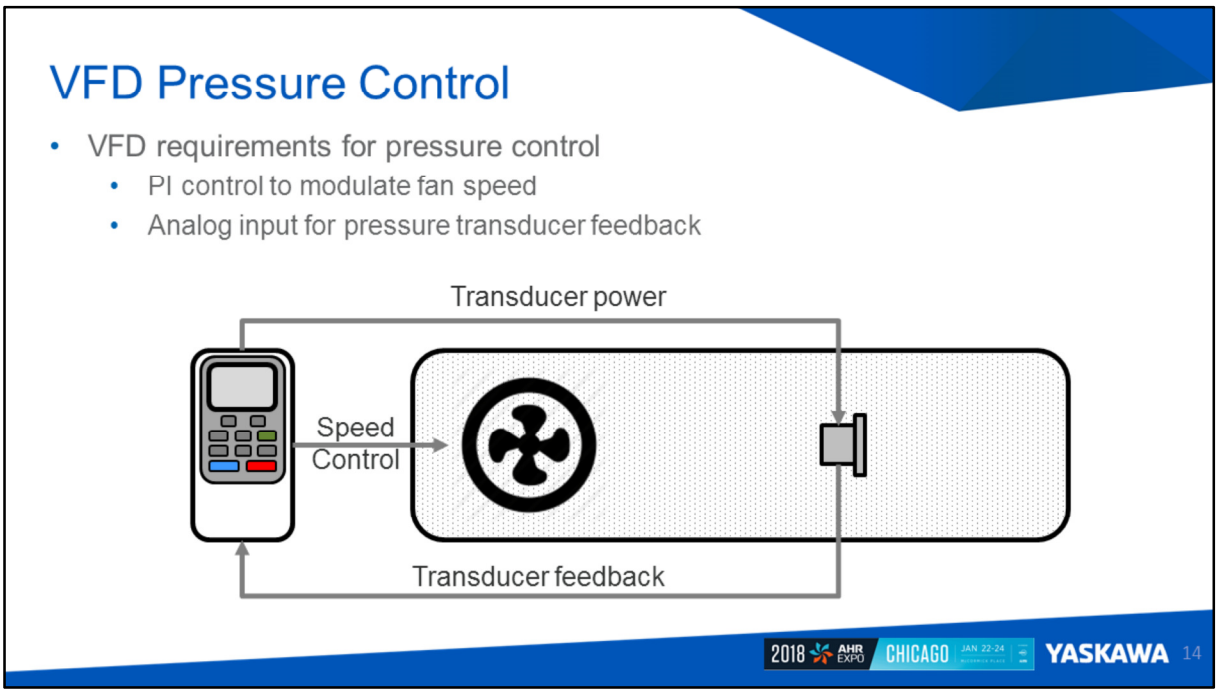
In both of these modes, the VFDs faceplate controls are disabled and they are set to "run to destruction," again because VFDs can be sacrificed in order to protect people.



Positive pressure is used to provide a safe exit path for building occupants.

For all except single-story buildings, the exit path during a fire event is almost always the stairway. And the usual means for the HVAC system to keep the stairway safe is to pressurize it to prevent smoke infiltration from the source.

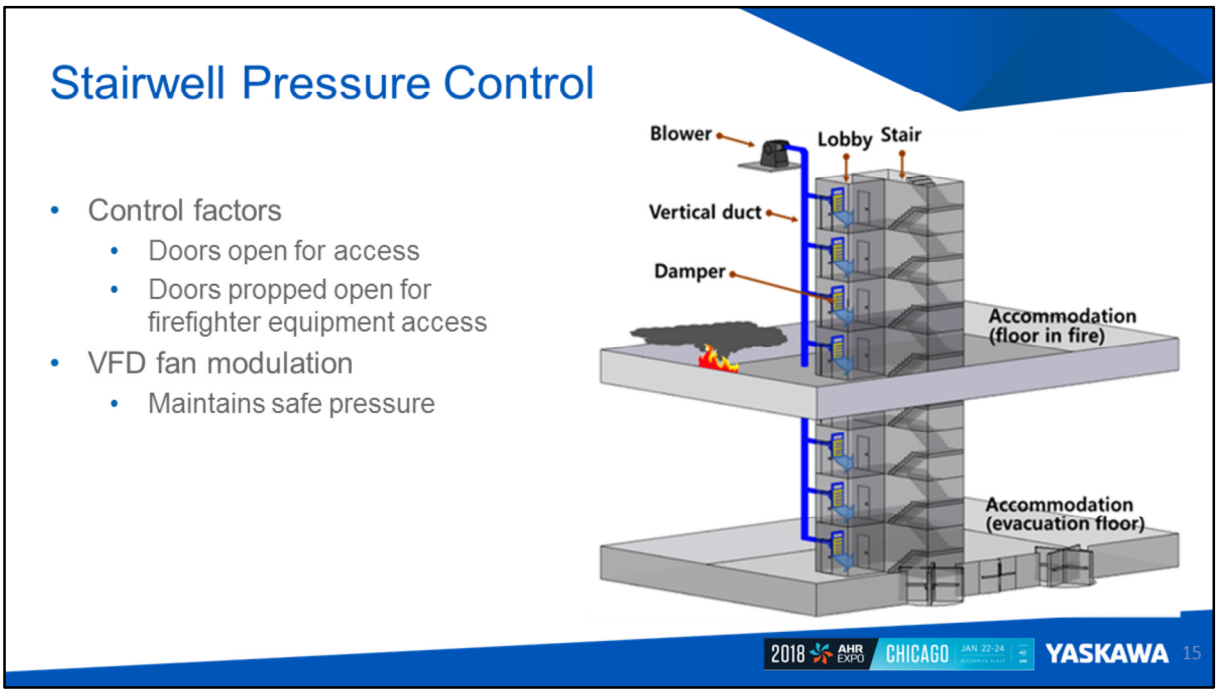
However, this is not always as simple has having the VFD run the fan at full speed. There have been documented cases where fans at full speed pressurized stairwells to the point where those attempting to get away from the fire could not overcome the pressure on the door to gain entrance. Codes vary by location, but usually they prescribe a limit of 30 pounds or less force to open the doors, which means the building engineer must calculate maximum allowable pressure very carefully.



Using a variable frequency drive to control the stairwell pressurization fan can assure the proper safe pressure level, provided it meets two critical functionality requirements.

The first is Proportional-Integral control. The PI function will modulate the fan speed to maintain a pressure set point based on feedback from a pressure transducer in the stairwell. The specified pressure will need to be higher than the area of fire origin to keep the smoke out, and equal to or lower than the maximum to meet local code for safe door opening.

This will enable the VFD, independent from any PLC or Building Automation System (that may be compromised), to adjust the fan speed to accommodate changes in door status.



But maintaining the proper pressure has some challenges.

In order for occupants to use the stairwell, they must, of course, enter through a stairwell door. When a door is opened, the pressure is relieved.

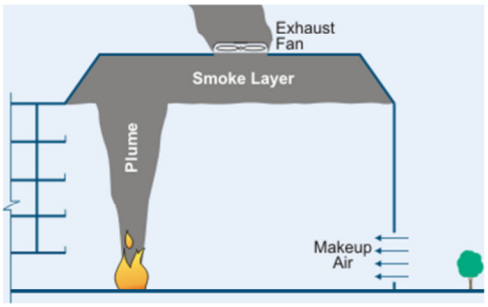
Many jurisdictions oversize vertical pressure fans to account for the leakage rate of construction and many other field conditions. Some jurisdictions require static settings where the VFD is set to run at a fixed, predetermined, and balanced speed.

Others require dynamic systems that can modulate to accommodate various simultaneous door openings, and in some cases, do not allow bypass units so as to prevent the possibility of the motor running across the line at full speed.

This is where the VFD internal PI control reacts to changes in pressure by increasing or decreasing the fan speed. When the pressure drops when a door is opened, the VFD speeds up the fan to compensate and maintain the safe pressure. When the door is then closed, the VFD backs off the speed to maintain the set point. The pressure transducer is typically connected to a VFD analog input to give the VFD constant real-time pressure readings.

Good Air to Breathe

- Smoke Purge to get the smoke out
  - VFDs create a negative pressure
  - Pull smoke out
  - Pull fresh air in
  - Run to destruction
- Pressure within safe limits
  - Internal door openings



Different from exit path pressurization, smoke removal means using VFDs and fans to exhaust the smoke and harmful gases.

Good air to breathe generally means getting the smoke out and fresh air in to the occupied space. In these situations, VFDs are usually put into Smoke Purge mode, which means run the fan at full speed, a preset speed, or modulated speed and “run to destruction.”

The objective here is to keep the smoke and harmful gases above the people in the highest occupied floor.

The VFDs run the fans to pull the smoke out and the supply air is sometimes controlled to create the negative pressure. But here also, there are limits. A maximum pressure differential is important to keep door opening and closing forces within code for internal doors.

Fan Status Problem Indication

- Undertorque detection
  - Senses less-than-normal motor load
  - Usually indicating a loss of mechanical coupling
  - Most codes require multiple belts for fire mode operation
- Overtorque detection
  - Senses more-than-normal motor load
  - Usually means a jammed or stuck fan
- Each event triggers its own digital output in the VFD
  - Signals sent to Fire Control Panel

In addition to fan speed control, firefighters require positive status of fan operation at the Fire Fighters' Smoke Control System (FSCS) Panel. They want to know, at the panel, whether the fan is running properly, and if not, the nature of the problem. The VFD can monitor motor current draw to detect a wide variety of problems that would cause the fans to not move air as needed. Here, Undertorque Detection senses too little current draw and Overtorque Detection senses too much.

These functions can be used to expose extreme problems like a broken fan belt or other mechanical coupling failure where the current drops suddenly, or a current spike resulting from a jammed fan, locked rotor, or some other mechanical problem that keeps the motor from turning the fan.

But the sensitivity can also be adjusted to sense more subtle changes where too much or too little air is being moved, like wind currents, or filters or ducts that are blocked. Each of these separate VFD functions will trigger its own separate digital output that can be used to ring a bell, light a light, or turn on some other indicating device.

All of which brings up the final item to discuss – the Fire Control Panel.

The Fire Alarm Control Panel is mission central for firefighters to respond to a building's fire event.

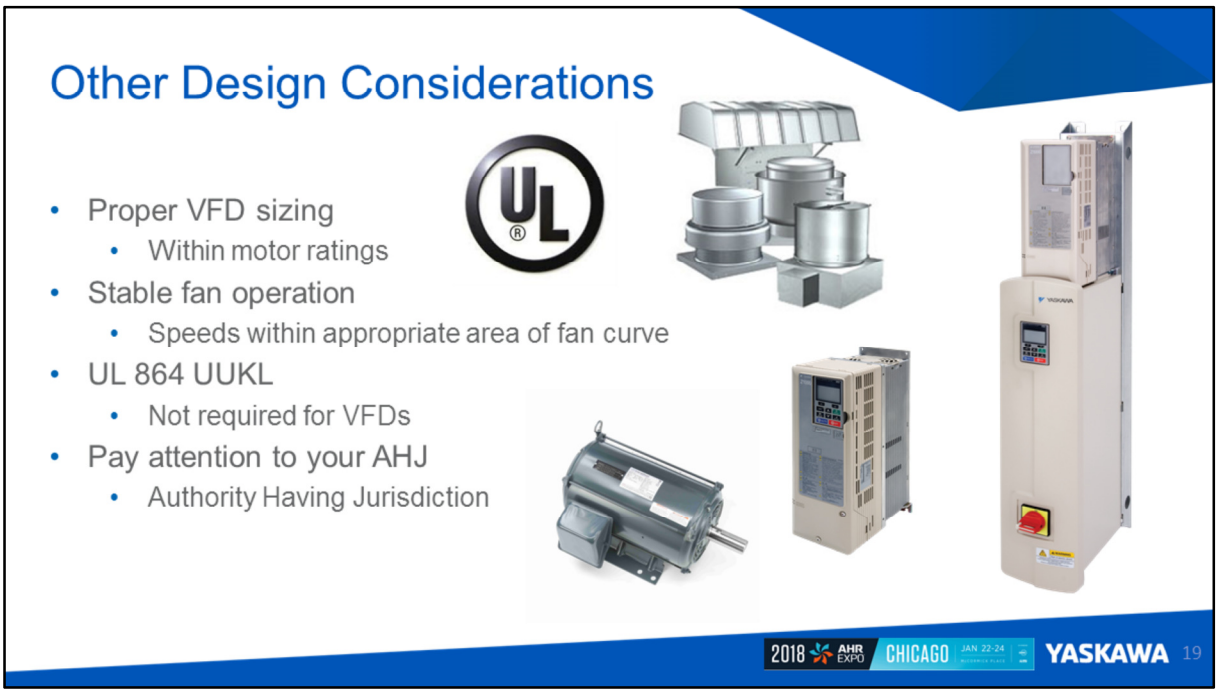
The fire alarm control panel, fire alarm control unit, or simply fire alarm panel, is the heart of the fire alarm system. The panel receives information from devices to detect and report fires, monitors their integrity, and provides for automatic control of equipment. The panel may also supply power to operate any associated devices.

So it's obvious there's a lot going on in the fire alarm control panel. What we're concerned with here is how it interacts with the HVAC system, and specifically, with VFDs.

The Fire Alarm Control Panel, with its attached sensors and internal logic, can instruct the VFD by a digital input to go into smoke purge or emergency override mode. The VFDs then act according to their instructions to drive a fan to exhaust smoke or to maintain exit stairwell pressure.

This is also where the VFDs will send their torque detection signals in the event of a fan problem. And, if no problems are indicated, the responders have positive indication that the fans are operating correctly.

It's all about safety, and during a fire event, information is key. If the firemen are confident the VFDs are doing their jobs to purge smoke and keep stairways clear, they can confidently go about their business of attacking the fire.



Besides the basic VFD requirements we'll summarize next, there are a few other design considerations for proper application of VFDs for fire situations.

First, as always, the VFD must be properly sized for the nameplate rating of the motor that drives the fan. And, the fan should be selected along with the motor and VFD to assure its airflow rates are within the overall range of the fan speeds for stable operation.

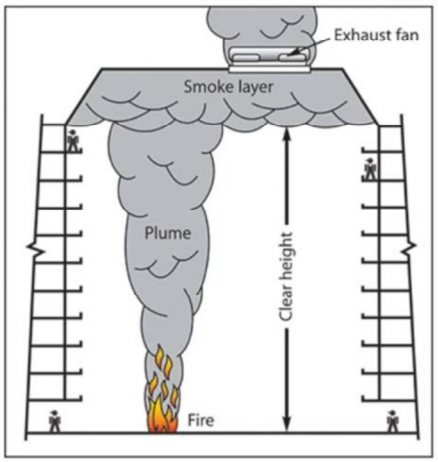
And the VFD should be protected. Critical safeties that could create a fire situation at the VFD should be maintained in service. Many jurisdictions require VFDs used in smoke control to be located within tempered, fire-rated rooms that are secured from tampering. If not in a secure room, they should be housed in the proper NEMA-rated enclosure for their location. And, note that fire alarm equipment is not permitted within the VFD enclosure.

Lastly, there is lingering confusion in the marketplace regarding VFDs and UL 864. UL 864 and its UUKL indentifier apply to Smoke Control Equipment like the Fire Alarm Control Panel. The key here regarding VFDs is the term "control." For UL 864 UUKL specifically, VFDs are recognized as end devices, along with motor starters, because their potential failure affects only the driven device and not any other part of the smoke control system.

And, of course, the local Authority Having Jurisdiction always has the final say.

VFD Safety Requirements

- Smoke Purge
  - Trigger(s)
  - Selectable faults to ignore
- Emergency Override
  - Properly modulate fan speed
    - PI control
    - Transducer feedback
- Equipment status indications
  - Broken belt
    - Undertorque detection
  - Jammed fan
    - Overtorque detection



So, in some ways, it's really quite simple. In addition to the myriad capabilities of VFDs, there are a critical few that are needed to do the most we can for occupant safety during fire events.

In Smoke Purge mode, the VFD will run the fans to push smoke out and pull fresh air in, either at a fixed or modulated speed.

In Emergency Override mode, the VFD controls fan speed to maintain the proper pressure in exit stairways to prevent smoke infiltration when doors are being opened and closed.

And for both modes, the VFD should "run to destruction" and monitor motor current draw to provide a signal when the current is either too much or too little.

So, I'm hopeful that you've gained some information that will help in your efforts to utilize VFDs to help assure occupant safety in building fire situations.

I have a few copies of a handout available here that provides information for a specific example of applying a VFD for stairwell pressurization. And, if you'd like a copy of this presentation, please drop off your business card here before you leave, and feel free to take one of mine.

And stop by the Yaskawa booth this afternoon for some free flavored popcorn.