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APPLIANCE & HVAC REPORT

Reaching Design Engineers at the OEM Level

July 2022 VOLUME 4 ➢ NUMBER 3





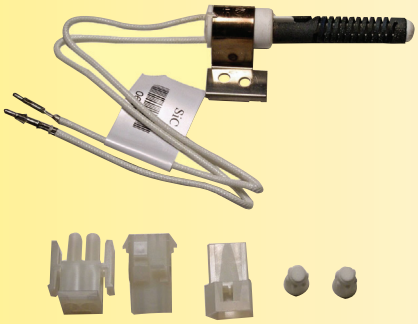
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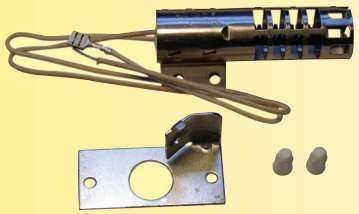
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Welcome to our July issue, the third of 2022



Hello readership. Just returned from exhibiting at the Electrical Wire Technology Processing Expo (EWPTE) in Milwaukee. Our first time there. Learned a lot and met a lot of people I didn't know previously. A great event and we will exhibit there in the future!

This issue has bonus circulation over and above our digital database. We are exhibiting at the Foam Expo, which is co-located with the Adhesives and Sealants Expo. It's in Novi, MI and will be our first time showing there too. We are doing our best to get to as many venues as possible.

This issue also marks the completion of our third year of publishing The ***Appliance & HVAC Report***. Things are going well and we look forward to supplying you, our design engineering audience, more technical materials in the future.

I would like to bring particular attention to our cover story "The Dismantling of Westinghouse", by David Durocher of IEEE. If you have been around awhile, as I have, you remember they were in multiple industries, including appliances. It's a fascinating story and well worth your attention.

We want to tell you about a new potential venture. Specifically, we are thinking of starting a new brand to complement our current title. But this would be called The ***Appliance & HVAC Report CSR***. The CSR stands for ***Case Study Review***.

It will consist entirely of case studies from suppliers to OEMs or OEMs themselves, that detail how they solved various problems. It should be very enlightening and helpful to our 24,000 subscribers. Look for it before year end. ***So if you/your company has case studies they would allow us to publish, to share your knowledge with others, feel free to send them to me at brad@appliancehvacreport.com.***

I also am happy to report I spoke at the June 7 meeting of the American Society of Gas Engineers www.asge-national.org, which has partnered with us.

As usual we have a broad list of companies who have submitted articles to us. In addition to the Westinghouse article mentioned above, here they area: Ametek, Coat Zone, DLS Electronic Systems, HBK, Littelfuse, Owens Corning, Superior Sensor Technology and Vitrek. Thank you one and all.

Enjoy the summer, please keep in contact and if we can be of any service feel free to call or email.

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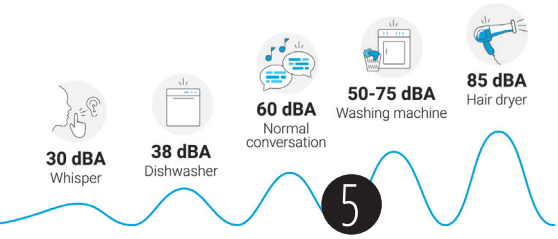
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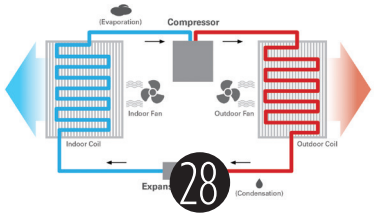
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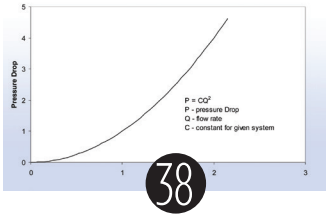
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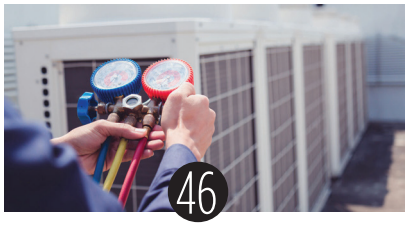
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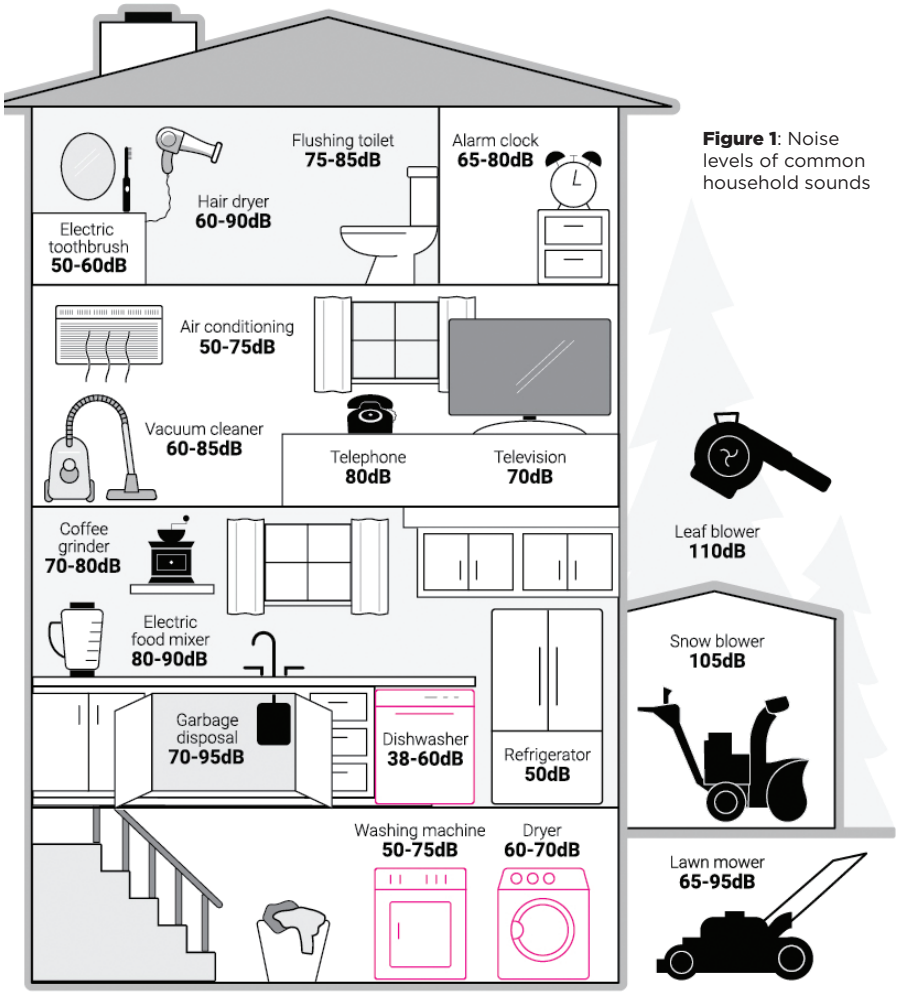


Figure 1: Noise levels of common household sounds

A Sound Strategy for Lowering Laundry's Noise Load in the Home

BY KEVIN HERREMAN

From refrigerators and ranges to water softeners and clothes washers, most major home appliances are designed for installation in a specific part of the house. The arrangement of appliances typically prioritizes efficiency and the range of actions taking place in a space. The "kitchen triangle" placing the refrigerator, cooktop/oven and sink/dishwasher in a predictable arrangement is a good example of orienting appliances to complement the flow of movement between preparing food and cleaning up. But what happens when floor plan designs evolve and home appliances move from more isolated parts of a home to areas where sleeping, working or enjoying entertainment take place? What are the consequences of appliance noise when it comes to occupants' comfort, concentration and overall enjoyment of a space? In this article, we'll consider how changes in home design are creating challenges when it comes to managing household noise. We will also consider how learnings from efforts to reduce dishwasher noise may be applied to curb the noise load coming from a home's laundry area.

An evolution in floorplans leads to appliance migration

As homeowners' lifestyles have evolved, so have home floorplans. Aging in place has led to more master bedrooms being located on the first floor. Family members consolidating households during the pandemic spotlighted the practicality of mother-in-law suites. As more homeowners work and study at home, online searches for acoustic solutions reveal a desire for quieter spaces.

The location of a space reserved for a perennial household chore has also shifted and laundry rooms are relocating in many homes. Clothes washers, long relegated to the basement or garage in older homes have migrated into homes' main living areas. As the bedroom is typically a space reserved for changing clothes, some home designs place the laundry facility on a home's second level near the bedrooms. Other designs place the laundry in a "mud room" on the main floor, which is often located near an entrance in proximity to kitchens or entertainment areas. But floorplans that prioritize convenience can come with the unwelcome consequence of higher noise levels (Figure 1) due to various sources throughout the home. The good news is that history shows that analyzing the sound emission of an appliance and designing a strategy to help consumers evaluate noise as part of the appliance buying decision can lead to quieter living areas.

A precedent for quiet: sound insights courtesy of the kitchen

Although today's dishwashers are so quiet that manufacturers have included lights to indicate the dishwasher's operating status, this wasn't always the case. Just a few decades ago, dishwasher noise was so disruptive that appliance ads featured consumers' frustration at being unable to enjoy a phone conversation in the kitchen when a noisy dishwasher was running. As manufacturer research demonstrated that consumers considered a dishwasher's noise level when making purchasing decisions, marketers sought to promote "quiet" as a purchasing attribute. Ad campaigns promoted dishwashers with names such as "Quiet Wash," "Silent Wash," and "Ultra-Quiet Wash." Despite marketing claims and clever names, the consumer had no objective standard for evaluating various models. Similarly, retailers lacked standards beyond a unit's name for determining how quite a product actually was in operation.

Against this cacophony of marketing messages, a major appliance retailer approached the Owens Corning Acoustic Research Center to help manage the acoustic challenge in the kitchen. The goal was to develop a measurement standard that could be used as an objective rating for dishwasher sound levels enabling consumers to compare and contrast when making purchasing decisions. The sound rating was based on the average sound level emitted by the dishwasher throughout its entire wash cycle. The standard also included a dry cycle if the model contained a fan-driven drying system.

Consumers show an appetite for quiet

What was the market response to the rating system? Sales analysis reveals that what was good for reducing kitchen noise was also good for reducing prices. Consumers responded readily to the new sound labeling and soon, all dishwasher manufacturers were utilizing the Owens Corning Acoustic Research Center to provide sound ratings for their models. On the marketing front, brands were advertised according to their sound level. By the 2010s, brand segmentation for dishwashers matured and resulted in three separate branding levels – commodity, value and premium, with commodity having the highest decibel range (55 to 65), value having a decibel range of 45 to 55 and premium boasting a decibel level range between 35 to 45 – barely above a whisper (Figure 2).[1] As manufacturers noted that premium units provided greater profit, production of quieter dishwashers increased. Just a decade after the sound rating standard was adopted, the sound ratings of both the loudest and quietest dishwashers on the market dropped.1 Sound levels on the quietest units fell by 10 decibels, which is typically perceived as being half as loud.1 Beyond lower noise levels, consumers also enjoyed better pricing driven by competition in the sector to produce quieter units. The same premium dishwasher that had a sound rating of 50 in 2012 had a MSRP that was nearly $300 less in 2015.[1]

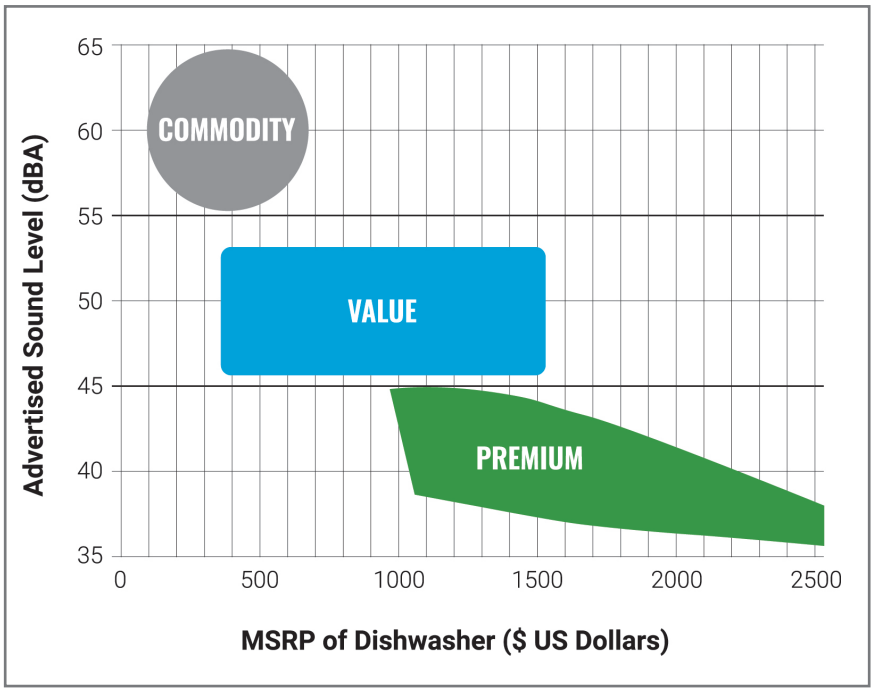


Figure 2: Labeling dishwasher noise according to three categories provided a standard for consumers to evaluate noise when purchasing a dishwasher

Considering the nuances of appliance noise

The nuances of appliance operation mean that a one-size-fits-all approach is not practical for indicating every type of appliance noise on a label. "Sound power" and "sound quality" are two approaches for evaluating sound. While sound power is adequate for assessing dishwasher noise, sound quality provides a more attractive path for measuring clothes washer noise.

What's the difference between these two measures and why is it important to consider sound power vs.

sound quality when labeling different appliances? Sound power refers to the magnitude (or volume) of acoustic energy emitted by an appliance during operation. It is different from what is sensed by the ear, which is known as the sound pressure level. Sound power is not influenced by the space where a noise-emitting appliance is installed.

A sound power-based standard works well for dishwashers because the characteristics of the sound frequency content (akin to "pitch" in musical terms) and amplitude (akin to "volume" in musical terms) are relatively similar to "pink noise" at most frequencies. Pink noise is a description of sound that contains all the sound frequencies that humans can hear. However, unlike the more commonly known "white noise," which represents all the frequencies having equal sound levels, the higher frequencies of pink noise decrease in level as frequency increases. As the sound level for a dishwasher is similar to pink noise across most of the measurement frequency range, the sound power measure is a good standard for labeling this appliance's noise.

Unlike the steady sound levels emitted by a dishwasher throughout its operation, the sound produced by a clothes washer is intermittent with a range of shifts between agitation, spin, fill and drain cycles. This type of sound is better assessed by a measure of sound quality. Varying frequencies of sounds that include tones, buzzes, clicks or hums change the listener's perception of the sound. For example, a car or motorcycle with a smaller or higher revving engine will be perceived to "whine," whereas a car or motorcycle with larger engine will be perceived to "rumble." While the sounds may objectively emit the same sound power, listeners are more likely to subjectively prefer the rumble over the whine by relating the lower frequency rumble to the amount of power the vehicle has. This subjective rating is referred to as "sound quality" and can be applied to more complex sounds. As the clothes washer operates across different cycles, this appliance is a good candidate for a sound quality labeling system.

A gap in the market and a chance to reduce appliance noise at home

While noise is often thought of as a nuisance, its effects can also be harmful. Beyond its ability to distract, community noise exposure (also called environmental noise, residential noise, or domestic noise) has been linked to sleep disturbances, and physiological concerns per the World Health Organization (WHO's) "Guidelines for Community Noise." The guidelines note "special attention should be given to noise sources in an environment with low background sound levels; combinations of noise and vibrations; and to noise sources with low-frequency components." Given the sound levels of clothes washers, this is a compelling case for developing a rating scheme and addressing their sound levels.

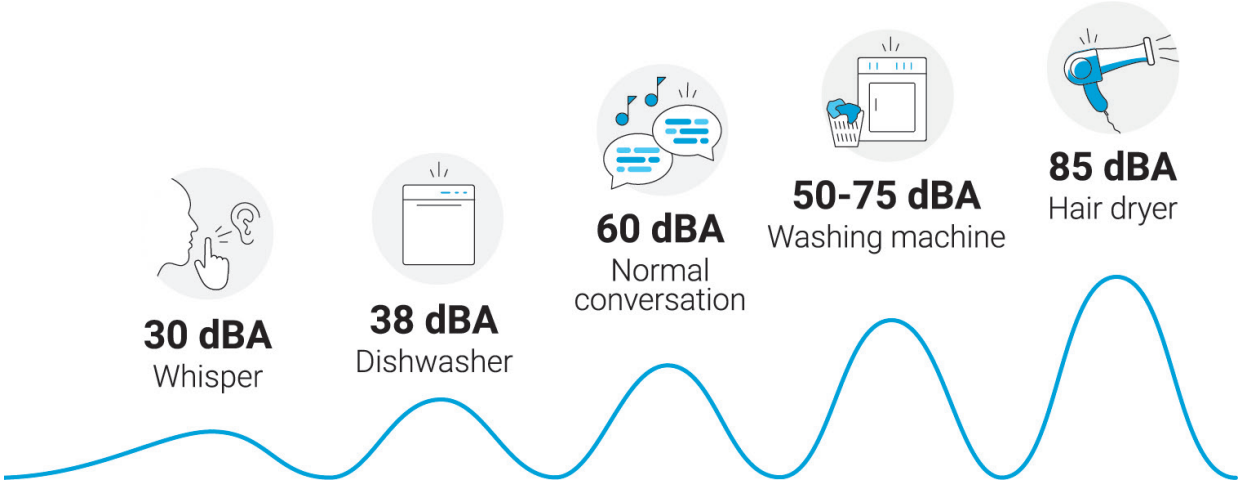
In the U.S. today, there is no objective, third-party testing standard for assessing sound quality in clothes washers. Consumers in the market for a new clothes washer primarily make purchasing decisions based on capacity, energy, price, and aesthetic/design features such as color. As the effort to label and categorize dishwasher models based on sound demonstrates, the adoption of a third-party standard for evaluating sound quality on clothes washers could reduce the noise load posed by laundry and help dial down appliance noise in America's homes. ●

References:
1. Herreman, K.M. (2016 June) Market effect on sound ratings for dishwashers. Proceedings NOISE-CON 16, 13-15, Providence, RI, edited by Gordon Ebbitt and Courtney Burroughs, paper no.nc16_159 (Institute of Noise Control Engineering Inc., Washington DC).

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Kevin Herreman *is the Principal Acoustic Scientist, Owens Corning and Melanie Knight, Products and Programs Manager, Owens Corning.*



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FIGURE 1. In the movie titled The Current War, George Westinghouse (Michael Shannon) and Thomas Edison (Benedict Cumberbatch) presents two powerful and enigmatic figures.

The Dismantling of Westinghouse

BY DAVID DUROCHER

In the late 1970s, hundreds of young engineers graduating from universities in many countries across the world started their professional careers working for Westinghouse Electric Corporation. The author of this article began his career at Westinghouse upon receiving his bachelor of science degree in electrical engineering. Back in those days, Westinghouse was one of the world's premier electrical businesses, a global innovator and manufacturer of electrical power systems, radar, nuclear energy and many others. Today, the company no longer exists. This article tells the story of what happened and offers insight on why it did.

The Day It Ended

On December 1, 1997, the Westinghouse Electric Corporation ceased to exist. The 111-year-old Pittsburgh, Pennsylvania, diversified industrial business founded by George Westinghouse in 1886 simply disappeared. On this fateful day, about three dozen company retirees and employees gathered on the granite steps outside the 23-story Pittsburgh headquarters building as Westinghouse was officially renamed CBS Corporation [1]. The global electrical products and services giant that 30 years earlier consisted of 172 operating divisions was dismantled and sold off piece by piece. In 1997, only three divisions remained: the nuclear energy, government operations, and process control divisions. These too were subsequently divested. As of August 2019, the Westinghouse brand name is managed by Westinghouse Licensing Corporation, a subsidiary of Viacom-CBS [2]. What happened? How did this electrical giant abandon its roots to become a major broadcasting company?

In the Beginning

The movie The Current War [3] is an American historical drama film inspired by the 19th-century competition between Thomas Edison and George Westinghouse (Figure 1) to power the modern world with dc or ac. The film sets the stage in the year 1880 as Edison first announces one of his many great inventions, the electric light bulb. At the time, his plans were to distribute power to American neighborhoods using dc, which was cheaper and cleaner than gaslight. Westinghouse was profiled in the movie as an "industrialist" with a much

lower profile personality than the more boisterous and arrogant Edison. Edison and Westinghouse compete to get cities across the United States to use their respective systems with the film culminating in a competition to illuminate the 1893 World's Columbian Exposition in Chicago celebrating the 400th anniversary of Christopher Columbus' arrival in the New World in 1492 [4]. Because the Westinghouse ac-based system demonstrated the ability to distribute power over longer distances at a lower cost, the 1893 Chicago World Expo was illuminated with the Westinghouse ac system. Two years later, Westinghouse installed the first hydropower ac generators at Niagara Falls, New York. Considered to be the largest hydroelectric power generation site of its era, the two-phase, 25-Hz ac generators developed 37 mW of power, supplying electrical energy not only to Niagara Falls but also to the city of Buffalo, 22 miles away, via a 11,000-V transmission line [5]. The future of ac was secured.

Edison, embarrassingly defeated and nearly broke from investing in his dc initiatives, turned to investors looking to start a new utility. In the movie, Edison met with his primary financier, then-famous banker J.P. Morgan, and suggested that his new utility company using dc generation and distribution to power his invention of the electric light bulb should be named Edison Electric Company. Actor Matthew Macfadyen, portraying Morgan, comically quipped that the company name needed to be something more generic—perhaps the General Electric Company! This was good theater, but it's only partially true. We learned from the "History" article in the last issue of IEEE Industry Applications Magazine [6] that Edison's existing business was indeed financed by Morgan, but in 1892 Edison's existing business, Edison General Electric Company, merged with Thomson-Houston Electric Company, and it was at that time that the name was changed to the General Electric Company.

Inventor Nikola Tesla is also featured in the film, arriving in 1884 as an immigrant from Croatia where he studied math and physics at the Technical University of Graz. He was hired as an engineer at Edison's Manhattan headquarters. After working there for a year, he and Edison had a falling out over equitable compensation for his inventions. In 1887–1888, Tesla was granted more than 30 patents for his inventions and research in ac. He was invited to address the American Institute of Electrical Engineers (which, in 1963, merged with the Institute of Radio Engineers to become IEEE) to share his work. Tesla's lecture caught the attention of Westinghouse. Westinghouse hired Tesla and licensed his ac motor patents and gave him his own lab in 1890. In the end, it was Tesla and development of his polyphase motor [7] that served as the key to the Westinghouse victory in the current wars and the ultimate proliferation of ac-based systems. The charter to establish Westinghouse Electric Company was first granted in 1886.

Screenwriter Michael Mitnick's research of Westinghouse via support from Pittsburgh's History Center helped to put the pieces together to get a glimpse of what George Westinghouse was all about. Since the charter was first established for Westinghouse Electric Company in 1886, Westinghouse devoted himself to his work. He never smoked, drank, or visited doctors. He spent most of his time in the shop and constantly professed his greatest motivation was in measuring what his company contributed to society. Mitnick said, "It feels almost silly to think he could be so selfless, but that's largely who he was. Westinghouse gave his employees homes with running water and heat. He built hospitals next to his factories. He was the reason company employees had Saturdays off. Westinghouse thought he would get better work if his employees were more relaxed and had a chance to blow off steam playing an afternoon of baseball."

Although most of his electrical inventions were licensed, Westinghouse was a prolific mechanical inventor. His air brake invention, for example, used compressed air to apply pressure simultaneously to rail cars, enabling a train to stop quickly and evenly. He received three dozen patents for reduction valves, expansion pipes, and other devices that could distribute natural gas safely from the ground to homes and factories. He tested his theories on a 300-ft natural gas well that he had drilled in his back yard in Homewood, Pennsylvania. He retired as chair of Westinghouse Electric Company in 1909 after receiving 361 patents for his inventions and founding 60 businesses. He moved to Lenox, Massachusetts, and died in a wheelchair on 12 March 1914 at the age of 67. Beside him was a set of drawings for a motorized electric wheelchair for which he was developing a design [1]. In 1989, 75 years after his death, Westinghouse was inducted into the National Inventors Hall of Fame.

The Turning Point

In the years to follow, Westinghouse Electric Company continued to expand, establishing new products and developing new electrical businesses. In

1917, Westinghouse introduced the fully automatic electric range. 1928 marked the year the company launched the first thermal- trip circuit breaker and first television camera tube. The Laundromat and first flexible-mounted automatic washing machine followed in 1940. The company changed its name to Westinghouse Electric Corporation in 1945. In 1953, Westinghouse built an atomic engine that became the prototype for the USS Nautilus, which was launched two years later. Westinghouse Credit was created in 1954 to finance sales of Westinghouse televisions, refrigerators, washing machines, and other appliances. The world's first full-scale atomic electric power plant at the Shippingport Atomic Power Station in Beaver County, Pennsylvania, marked the company's first excursion into nuclear power plants in 1957 (Figure 2). In 1972, the Westinghouse Airborne Early Warning and Control System (AWACS) was launched. The radar system, deployed on military jet aircraft, includes a plane-mounted rotating dome, providing 3D, 360° surveillance for up to 200,000 square miles around the aircraft, or 250 miles in all directions.

Donald Burnham graduated as an engineer from Purdue University in 1936. Following service in the U.S. Army during World War II, he was recruited to serve as manufacturing manager and assistant chief engineer for the Oldsmobile division of General Motors. He joined Westinghouse in 1954 as vice president of manufacturing at the age of 39. Eight years later he was elected to become Westinghouse CEO (1963–1968), continuing as chairman and CEO (1969–1975). When Burnham took the helm, the company's sales had been stuck in the US$2 billion-a-year range for nearly a decade [1]. He decided that the corporation, which now included 135 operating divisions, needed to be reined in. Many of the businesses were performing, but few offered opportunity for growth. One significant "problem child" was the appliances business, where existing plants were outdated and in need of investment to remain competitive. Westinghouse products were highly engineered and considered to be superior to those offered by competitors. The front-loading washers used less soap and water, and clothes came out cleaner - and everyone knew it (Figure 3).

The company's well-recognized slogan, "You can be sure if it's Westinghouse," coupled with the best products, should have delivered significant market share and profitability. But General Electric commanded 40% share of the appliances market, and another 30% was controlled by Whirlpool and Sears. This left Westinghouse with a 7% market share, followed by a handful of others including White Consolidated Industries and Frigidaire. As the nation began to enter a deep recession in the early 1970s, the appliances market fell. Losses for the appliances business peaked at US$200 million in 1972. Burnham bit the bullet. He sold the business to White Consolidated for an after-tax loss of US$55 million. He was criticized by the investment community that suggested the company would have saved money by simply closing down the operations. Burnham felt responsible to the nearly 10,000 employees, most who worked at three Ohio-based plants. This was a noble gesture by Burnham that certainly would have made George Westinghouse proud. During Burnham's 12 years at the helm, he was successful in pushing Westinghouse forward as sales almost tripled to US$6 billion and employment nearly doubled to

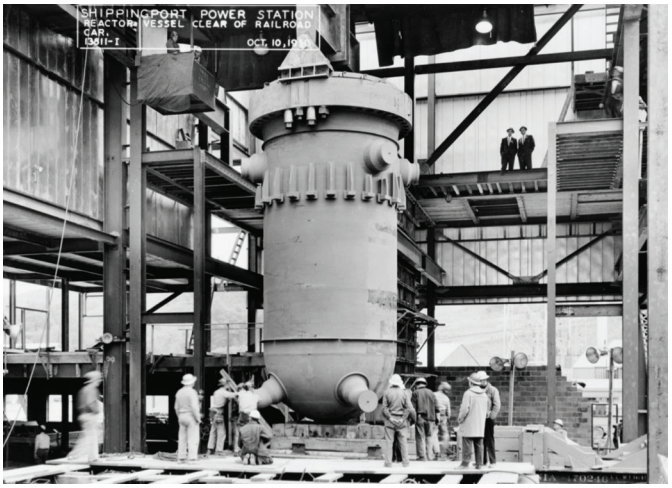


FIGURE 2. Shippingport Atomic Power Station: reactor pressure vessel during construction (1956). (Source: United States Library of Congress, used with permission.)



FIGURE 3. The Westinghouse Laundromat and its companion dryer, invented in 1954, which was famous for its tiny xylophone rendition of "How Dry I Am" [11]. (Used with permission from Timothy Brian McKee.)

199,000. He moved the company into new fields such as rapid transit, soft drink bottling, and Florida land development. The Westinghouse Credit division remained with the company after appliances were divested to White Consolidated. Retaining the credit business would prove to be a decision that enabled the future dismantling of Westinghouse - a costly mistake.

The Uranium Detour

Robert Kirby succeeded Burnham in 1975 and was Westinghouse CEO until 1983. Like Burnham, Kirby was a native of Pittsburgh and received a bachelor's degree in chemical engineering from Penn State in 1939. In 1943, he joined the Navy's highly secret radar corps. He was sent to study electrical engineering at Princeton University, the Massachusetts Institute of Technology, and Bell Labs. In 1946 he was discharged from the military with the rank of lieutenant after serving as an electronics officer [8]. He joined Westinghouse in 1946, left in 1954 for a two-year hiatus while completing his MBA at Harvard Business School, and returned in 1956 to serve as general manager of the electronics division. He was another ''insider'' and an obvious quick study: Kirby liked to challenge Westinghouse senior managers to solve a Rubik's Cube, a popular puzzle of the time, a feat that he could accomplish in 72 seconds.

Within weeks after becoming CEO, Kirby was surprised to see the price of uranium begin to soar. The normal price of US$5 - $6 per pound had more than doubled. This was a problem, since at the time Westinghouse built or designed more than four of every 10 nuclear plants in operation around the world. Long-term contracts with utility customers included agreements to sell uranium to fuel the emerging new source of power generation. By mid-1975, uranium prices surpassed US$40 a pound. With 20-year agreements to provide over 65 million pounds at prices more than US$30 a pound higher than its contracts with utility customers, potential liabilities exceeded US$2 billion. Westinghouse had no other choice than to renege on its contracts. This, of course, prompted lawsuits from 27 utility customers [1]. Already a chain smoker, Kirby started lighting up even more as he pushed to somehow resolve the uranium problem. Kirby decided to devote his full attention to the uranium issue. It was clear that, if left unattended, this could sink the company. After meeting with the Westinghouse board, an agreement was reached to split duties to lead the corporation, bringing in Douglas Danforth, then Westinghouse president of the industrial group, to become vice chair and manage day-to-day operations, leaving Kirby singularly focused on solving the uranium issue.

Kirby caught a break. He determined the reason for skyrocketing uranium prices. Gulf Oil, one of the company's uranium suppliers along with 28 others, had formed a cartel, conspiring to extricate Westing- house from the uranium business. He secured documents including minutes from a private meeting in Australia of uranium suppliers that proved existence of the cartel. The documents had come from an unlikely source, the environmental group Friends of the Earth [1]. Westinghouse quickly mounted lawsuits against Gulf and other members of the alleged cartel to save the company. In late 1979, after a flurry of lawsuits were settled, Westinghouse agreed to concessions that would cost almost US$1 billion before taxes. Thankfully, the total liability turned out to be much less [8]. Uranium suppliers settled out of court, agreeing to pay Westinghouse a nearly US$100 million cash settlement while still retaining their obligation to provide uranium as stipulated in the long-term contracts. Also, settlements with utility customers called for Westinghouse to provide parts and services at discounts for up to 25 years, which effectively locked in long-term customer agreements. Even with the discounts, Westinghouse would still make money on the supply contracts.

Kirby learned late in his tenure of one unintended consequence of the decision to give the reins to Danforth while he resolved the uranium issues. Picking a successor other than Danforth would be difficult if not impossible! Kirby had his eyes on a few other successors, but Danforth had become popular with members of the board, and he was almost preordained to become the next Westinghouse CEO.

Show Me the Money!

In 1983, U.S. President Ronald Reagan was elected to begin his second four-year term. Free markets and capitalism abounded, and Danforth was clearly a man for the season. Danforth, a native of Syracuse, New York, graduated with a B.S. degree in mechanical engineering from Syracuse University in 1947. He joined Westinghouse

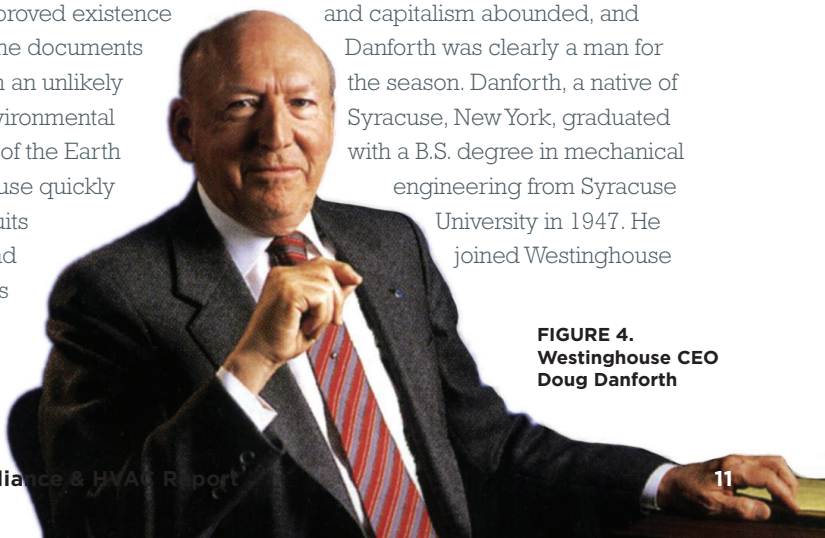


FIGURE 4. Westinghouse CEO Doug Danforth

in 1955 as an executive vice president and general manager, mastering the Spanish language while running a sister company, Industria Electrica de Mexico. On short order, he moved back to the United States and began working his way up the Westinghouse org chart in his newly adopted city of Pittsburgh. As the new Westinghouse chair at 61 years old, he would have only four years before he would be forced to retire at age 65. Danforth didn't have a lot of time - he would need to move quickly.

From the moment Danforth first sat in the CEO's chair, his focus was centered on raising Westinghouse's return-on-equity (the ratio of profits to stockholder value) to 20%, a margin enjoyed by only the most respected businesses. Westinghouse profit margins needed to improve, not this year but this quarter, or managers and operations would be on the chopping block. Danforth demanded that the business earn respect from the investment community and that the Westinghouse stock price was to be constantly on the rise.



FIGURE 5. This portrait from the 1980 Westinghouse annual report freezes a moment of togetherness for top management. At the center is Robert Kirby, chairman and CEO; clockwise from lower left: John Marous, CEO from 1987–90; Douglas Danforth, CEO from 1983–87; Gordon Hurlbert, Power Systems president, 1980; Thomas Murrin, Public Systems president, 1980; Edwin Clarke, Industry Products president, 1980; and Leo Yochum, senior executive vice president, finance. Westinghouse Licensing, with permission.

Everything about Danforth was about maximizing profits, from the corporation to his personal life. He raised llamas and Christmas trees on his Washington County farm not just as a hobby but for money (Figure 4). Customers who liked haggling over the price of a tree would find the US$26 price was not negotiable. There was no haggle with Danforth [1].

Westinghouse was on the move, and Danforth pushed the company into high gear. In 1984, the education- al and language product operations and industrial fan business were sold. The board approved a two-for-one stock split and raised the dividend. The dividend was raised again in 1985 when the company announced the sale of several Group W Cable Television stations for US$1.7 billion in cash. In 1986 he completed a buyback of 20% of common stock for US$1.6 billion, sold Muzak, and acquired an independent TV station in Los Angeles. The financial services unit was also on the move, announcing record income of US$115 million, 16% of corporate earnings in 1987. This was promptly followed by another raised dividend and final shutdown of the East Pittsburgh operations. Over the course of Danforth's four years at the helm, Westinghouse profits soared, profit margins almost doubled, and its stock price more than tripled. Making shareholders and Wall Street happy was easy, and more importantly it was profitable.

Before he left office, Danforth had one more job to do: choose a successor. One possible candidate was Paul Lego, a bright engineer

who'd worked for Danforth when he ran the industries group. Danforth had brought Lego into his inner circle, as head of corporate resources. But Lego was green - he'd never run a major operations group. Lego was a quantitative thinker in formulating strategies, but at times he came across as arrogant and condescending. At times it seemed he lacked people skills. John Marous, a baseball star at Perry High School and a University of Pittsburgh engineering graduate, was the other potential successor as chair. Marous had risen through the ranks to become a top executive. He had headed the international group since 1979 and also for the last three years oversaw industries, a business that had turned around dramatically as Marous and Lego sold or closed several marginal businesses and outdated plants. In the spring of 1987, Danforth recommended to the board that his successor be the 57-year-old Lego, asserting that Marous, who was 62, would not have enough time to meaningfully impact business growth and profitability. The board expressed doubts that Lego was ready. This, coupled with Marous outwardly expressing plans to sign his resignation papers, resulted in a compromise. Marous would be named chair from 1988 to 1990 and then he'd be succeeded by Lego (Figure 5).

Calm Before the Storm

Marous (chair and CEO, 1988–1990), by most every measure, led Westinghouse to further success. Profits expanded at double-digit rates, and sales of continuing businesses had also grown at this rate. The goal he had set at the beginning of his term, continuing with Danforth's challenge of return-on-equity above 20%, was met for three consecutive years. In many ways, Marous followed in the time-tested path of Danforth, continuing with ''portfolio engineering'' and moves that would be cheered on by Wall Street. In 1989, there was a deal to sell the US$1.4-billion-a-year transmission and distribution business to Asea Brown Boveri and the US$500- million-a-year elevator division to Schindler. The dividend was raised every year. This was topped off with a two-for-one stock split, approved by the board in the third and final year of Marous' three-year term.

To keep making it work, Marous needed to make sure his management team was feeling the heat. Mandatory 7 a.m. meetings to check his managers' progress were scheduled. The Westinghouse portfolio of businesses was categorized in three tiers: the A list of performing divisions, the B list of divisions that needed help, and the C list of divisions that were not performing to expectations. C businesses were slated to be sold, and B businesses needed to quickly find a way to be upgraded to A or they would drop to C. This rigorous business discipline helped, but Marous needed something more to produce even better numbers that would appease Wall Street. In 1988, William Powe replaced retiring John McClester as chair of the Financial Services Division, the lending arm of Westinghouse Credit. Powe, who came to Westinghouse from the real estate lending business, was a deal-maker. The once-sleepy Westinghouse Credit unit that formerly issued residential loans for the divested appliances division was transformed to become the new engine that would supercharge quarterly performance. It was actually Danforth who worked with outside consultants in July 1986 to develop a strategic plan for accelerated growth of Westinghouse Credit. The plan included speculative commercial real estate loans, direct loans to developers, and riskier but more lucrative corporate and junk bond financing [1]. Under Danforth, Westinghouse Credit profits had jumped from US$22 million to US$106 million between 1980 and 1986 and assets (primarily loans) went from US$1.9 billion to US$5.7 billion in that same period. Marous had a plan to crank things up faster and much higher.

A new group of young financiers was challenged to get money out the door fast. Marous had always been a competitive, get-it-done type. He didn't care to know much about loan details. He just wanted results - and he got results. Loans and other financial assets topped US$13 billion by mid-1990, more than double their levels in four years. Westinghouse Credit was hailed as the top performing unit in the corporation [1]. Then, things started to look to be getting a little shaky. The commercial real estate collapse of the mid-1980s looked like a possible threat to the business. Bank failures in the United States peaked in 1988 [9]. Powe and Marous didn't care. Westinghouse was on a mission: circling third base with plans to score the home run in June 1990, the date when Marous was scheduled to retire. Lego would be left to clean up the mess.

Coming Apart at the Seams

Lego (chair and CEO, 1990–1993) had a problem. A six-month investigation of Westinghouse Credit had revealed US$3 billion in bad loans, almost a quarter of the total out- standing. The investment community was getting nervous. New federal rules restricted the amount of commercial paper (short-term IOUs to big corporations with solid credit issue to raise funds at lower rates than banks) that

money market funds could own. Westinghouse's sagging stock price and news of a few loan defaults put a US$1.3 billion Westinghouse line of credit at risk. Westinghouse had a ''liquidity problem,'' a business term meaning the business had better do some- thing fast, or it would go bankrupt. Lego took swift action. He decided to restate 1990's record earnings of US$1 billion to make room for a nearly US$1 billion pretax charge-off to cover known bad loans. He decided to go for a US$975 million pretax charge, because the optics of a six-figure write down would look better to Wall Street. The 60-year-old Lego instantly dug a hole for himself with the board and in the investment community (Figure 6).


Westinghouse looks to sell credit unit

Westinghouse woe

$1.5 billion loss leads to 4,000 job cuts

Westinghouse faces severe realty losses

Half its loans fail; cash flow squeeze seen

Westinghouse seeks financing

Westinghouse rating slips

FIGURE 6. Paul Lego feels the heat as Westinghouse begins to unravel. (Source: Pittsburgh Post-Gazette, used with permission.)

Powe insisted that the US$975 million write down would be enough to get Westinghouse Credit back on its feet. Unfortunately, Poe's optimism was misplaced. Efforts to sell troubled properties that spring yielded little results. Potential buyers were avoiding real estate like the plague. Laurence Chapman, chief financial officer (CFO) at Westinghouse Credit, resigned. He feared possible legal ramifications if he signed required regulatory filings that he knew would contain false information. Lego fired Powe and brought in former Westinghouse CFO Leo Yochim to investigate and give him the full story. Beginning in October 1991, Yochim's thorough investigation of Westinghouse Credit lasted 13 months, revealing that Westinghouse would need to get rid of US$7.6 billion in assets and take an additional US$4.8 billion charge. In his 33 years at Westinghouse, Lego had demonstrated measured skill by turning around several troubled divisions including lamps, semiconductors, and distribution controls. It didn't seem fair that he was now consumed with a mess he didn't create, just after Marous had escaped an unscathed hero.

Westinghouse was quickly eating through a US$6 billion line of credit arranged with lenders in late 1991. It was clear that several businesses would need to be sold to raise cash. Lego's survival plan included shedding its electric supply, distribution and controls, office furniture, and land development businesses. He sold the idea to members of the board, but his fate was sealed. Lego was gone by January 1993, temporarily replaced by longtime Westinghouse executive Gary Clark. The search for a new chair had begun. It turned out to be the last one for Westinghouse.

The Turnaround Specialist

Michael Jordan (chair and CEO, 1993 –1997) earned an M.S. in chemical engineering from Princeton. He was not from Pittsburgh and had never worked for Westinghouse. He was an outsider, formerly working for McKinsey & Company as a consultant and principal (1964– 1974); PepsiCo Worldwide Foods, holding various senior executive positions, ultimately serving as CEO (1986–1992); and as a principal of Clayton, Dubilier & Rice (CD&R), a private investment firm (1992–1993). He was recruited as the first outside chair of Westinghouse Electric Corporation, sold to the board as a turnaround specialist. Jordan didn't have history, experience, or interest in the portfolio of Westinghouse industrial businesses. He saw the company as a dinosaur that badly needed to be reinvented.

Jordan had a look at the Westinghouse balance sheets and discovered the health of the business was worse than he expected. Over the past several years, many of the businesses had taken one-time write downs to prop up quarterly earnings. Over the coming months, his lack of respect for the senior management team showed. There was resentment from many of the insiders who perceived him as a consultant who never made anything and a marketer who was not fluent or familiar with the intricacies of Westinghouse operations and technology. A wave of consultants began to arrive at the headquarters building with strategic plans to ''rationalize the central organization'' or, more succinctly, cut bodies. Every time Jordan announced a new way of doing things, it was followed by a different group of consultants and a new round of layoffs. Over the next few years, debt was marginally reduced, but the business was stagnant.

Westinghouse needed a growth engine and didn't have one.

One of the legacy Westinghouse businesses was Group W broadcasting. In 1920, the company established KDKA, the nation's first commercial radio station. Broadcasting accounted for only 10% of Westinghouse's revenue but generated almost 25% of the profit. There was room to grow, but it would require scale and significant investment. Bill Korn, the head of broadcasting, for years had envisioned making a run at one of the networks, and here was his chance. Group W still owned five TV stations and 18 radio stations, and the profit-to-sales ratio for radio was 42% compared to CBS and other media giants whose business returned low single-digit profitability. In the summer of 1994, Rupert Murdoch snapped up eight CBS-affiliated stations in the startup of Fox, and the table was set. A Westinghouse CBS offer to buy out CBS would cost over US$5 billion. Banks were eager to lend money to finance this most profitable business venture, and they were happy to extend a new US$7.5 billion credit line to do so. On 2 August 1995, Jordan and CBS Chairman Laurence Tisch unveiled the deal amid much fanfare in New York [1].

In 1997 Westinghouse would finalize the official stock market transformation of Westinghouse becoming CBS Corp. They also went on a media acquisition spree that year, snapping up The Nashville Network and Country Music Television (US$1.55 billion) and American Radio Systems (US$2.6 billion). In January 1998, it would reclaim rights to be a National Football League broadcaster (US$4 billion over the next eight years).

It wasn't supposed to work out this way. Westinghouse Electric was supposed to survive as a separate industrial company from CBS under a continuing ticket symbol WX as outlined in the strategy unveiled in November 1996. But to fund the media spending spree, Westinghouse needed to sell off most of what was left of the company. This included the sale of defense electronics for US$3 billion, its land development business for US$430 million, Knoll office furniture for US$560 million, a residential security business for US$430 million, Thermo-King for US$2.56 billion, and the power generation business for US$1.53 billion. Westinghouse Electric Corporation essentially vanished into thin air (Figure 7).



FIGURE 7. (From left) New York Stock Exchange Chairman Richard Grasso, CBS Chairman Michael Jordan, CBS Evening News anchor Dan Rather, and actor/comedian Bill Cosby preside over the official stock market transformation of Westinghouse Electric into CBS on 1 December 1997. (Source: Associated Press, used with permission.)

A Final Epitaph

The survival of any business requires dedicated, visionary leaders with clearly stated and understood values. As a former employee of Westinghouse, the author was able to witness, first hand, a view of company values projected by one Westinghouse senior leader. Reminiscing about attending a business meeting with a top Westinghouse customer in the mid-1980s, at the time the author worked for Westinghouse as a first-level sales manager. A meeting was set with the CEO of one of America's fastest growing and most profitable steel producers. The Westinghouse regional vice president set up the customer meeting, primarily to thank the CEO for placing a new multimillion dollar order for essentially all of the electrics needed for the steel producer to build a new mill in the midwestern United States. At the time, Westinghouse designed and manufactured nearly everything electrical for this mill, including the rolling mill drive system, transformers, motors, switchgear, controls, and supporting components.

The meeting began, and after exchanging pleasantries, the discussion moved toward a comparison of the culture and values of the two businesses. The steel-producing CEO went first: ''Our three top priorities, in order of importance, are first - a commitment to our employees, second - a commitment to our customers and third - a commitment to our shareholders.'' He went on to explain that engaged and satisfied employees were at the heart of every company initiative. He shared that the steel producer proved this by both words and actions. He cited a few examples. There was no executive parking space closest to any of their mill entrances. The employee that got there early was rewarded with the best parking spot. He also mentioned that although many corporations donate money to university foundations to fund scholarships, his intentionally avoided donating to university endowments. Instead, his business established a foundation to support scholarships for the children of company employees. The CEO then explained the second priority: satisfied customers. This could be achieved only by executing on the first priority - having satisfied and engaged employees. Finally, he mentioned the third priority, a commitment to the shareholders, would necessarily be achieved as a result of commitment to the first two. The room fell silent as the Westinghouse managers shook their heads, signaling that they understood. The Westinghouse regional vice president then thanked his customer for these important insights. Embarrassed, he admitted that for Westinghouse, the priorities were first shareholders, then customers, and, last, employees.

In July 1992, Chairman Lego issued a ''View from the Chairman'' message circulated to all employ ees. He labeled this piece, ''My Road Map for the Future Success of Westinghouse.'' The Westinghouse purpose in all of its decisions and actions was broken down into eight specific goals, with the first being ''To attain a continuous high level of profit which places it in the top ranks of industry in rate of return on invested capital, recognizing that Westinghouse can serve society only if it is financially viable.'' Item 4 included a statement about ''customer responsiveness'' and item 7 finally mentioned ''encouraged and stimulated employees.'' The other five goals included language concerning the environment, productivity, efficiency, ethical standards, and legal standards.

Lego was well coached by his predecessors, and he clearly understood the culture and purpose of Westinghouse Electric Corporation. At this point, it seems the only thing left is history.

A Diamond in the Rough: A Final Perspective

The focus of this article has been based on a cultural transformation of Westinghouse Electric Corporation over its 111-year history. The perspective shared is based on decisions by company senior and executive leaders. Westinghouse Electric is not the first corporation, nor will it be the last, that vanished from existence because business leaders fell victim to short-term, profit-driven strategies, designed primarily to pacify the vultures of Wall Street. Beyond this, it is also important to consider the meaningful contribution of thousands of Westinghouse employees who, over 111 years, advanced science and technology to improve society and positively impact the lives of many. This too matters.

Many divested Westinghouse businesses have thrived under new ownership. A few examples include the former Westinghouse mass transit business, now Andritz, where employment doubled to over 1,800 worldwide by 1997. The former Westinghouse Heavy Industrial Motor business, now TECO-Westinghouse (not a Westinghouse company, but continuing with a brand licensing agreement) remains a global leader in design and manufacture of ac and dc motors. The once Westinghouse Thermo-King business is now a growing business for Trane, a division of Ingersoll-Rand Company [10]. The former Westinghouse distribution and controls business was acquired in 1994 by Eaton for US$1.1 billion and combined with Eaton's existing

US$500 million Cutler-Hammer electrical business. Today, Eaton's electrical business has grown organically and through acquisition to over US$12 billion. Across all regions of the world, a host of Westinghouse design and manufacturing engineers, as well as many other disciplines, left behind designs, products, patents, and fundamental engineering tools. Over the 111- year lifetime of Westinghouse, these advanced principles and disciplines in the field of electrical engineering and are applied extensively to this day (Figure 8).

While you were reading this

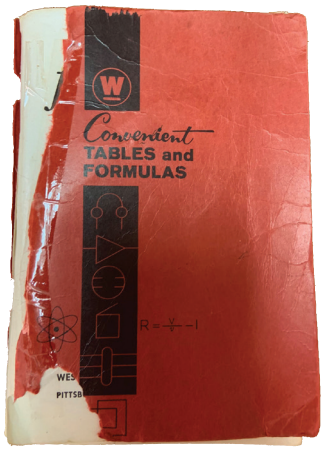


FIGURE 8. A vintage and well-used book of Convenient Tables and Formulas, 1977.

article, somewhere in the world, right now, a Thermo-King (now Trane) refrigeration system is transporting lifesaving COVID-19 vaccines to thousands of people in need.

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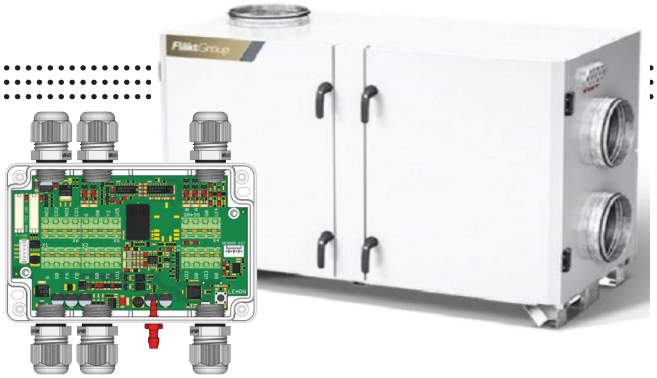
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Automated Logic has added advanced variable air volume (VAV) controllers to its **OptiFlex**™ line of digital building controls. Automated Logic, a leading provider of innovative building management solutions, is a part of Carrier Global Corporation (NYSE: CARR), the leading global provider of healthy, safe, sustainable and intelligent building and cold chain solutions.

The new OptiFlex VAV controllers, models OF342 and OF141, are ideal for zone-level temperature and air quality control applications. Designed to operate in a wide range of environmental conditions, the new controllers are ASHRAE Guideline 36 compliant with inherent algorithms that help reduce energy consumption and increase occupant comfort. To help maximize energy efficiency and performance, ASHRAE Guideline 36, High-Performance Sequences of Operation for HVAC Systems, includes uniform sequences of operation for HVAC systems, which help provide control stability and allow for real-time fault detection and diagnostics.

''These new OptiFlex controllers are well suited to satisfy the demands of variable air volume and temperature applications, giving customers peace of mind that their facilities will provide more comfortable and productive indoor environments,'' said Mead Rusert, President, Automated Logic.



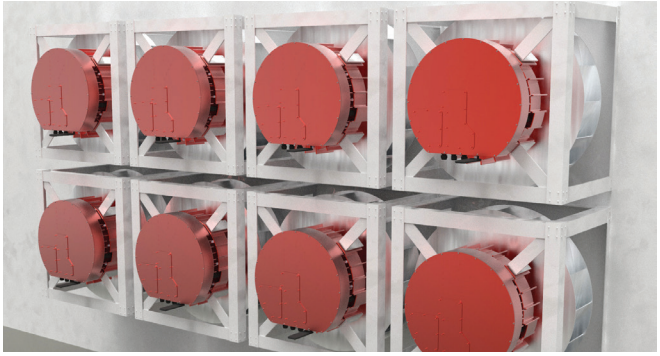
Superior Sensor Technology announced the **HV120 Differential Pressure Sensor** is used in the **FläktGroup** compact **eCO Side Air Handling Unit** for HVAC equipment. The HV120's proprietary Multi-Range™ technology coupled with an advanced integrated digital filtering feature enabled FläktGroup to easily design and manufacture a superior, compact Air Handling Unit for light commercial HVAC applications.

A differential pressure sensor is a critical component in insuring filters in air handling equipment are replaced or cleaned to optimize the performance of HVAC equipment. External noise can affect the accuracy of the pressure sensor reading causing premature and unnecessary filter replacements. The HV120 digital filtering feature eliminates the noise before it reaches the sensing element, enabling the eCO Side Air Handling Unit to operate at a low noise level of <35 dB(A) at 3m with no costly pressure measurement error readings.



The new **CD450** and **CD450V** control dampers from **Ruskin**® are extruded aluminum models that use a 4-inch-wide frame design with finger-style jamb seals for a "light-tight" sealing effect. The CD450 and CD450V – which have horizontal and vertical blade orientations, respectively – are ideal for any HVAC application that requires high, energy-efficient performance.

Both models were designed to control and regulate air movement in medium- to high-velocity and pressure HVAC systems. The CD450 and CD450V include airfoil blades with mechanically-fastened blade seals that offer low pressure drop – and less noise – when open and achieve Class 1A leakage (3cfm/ft2 at 1" w.g.) performance when closed. Acetyl copolymer blade end caps enhance sealing against finger-style jamb seals.



An extension of **Infinitum Electric's IEs Series motors** will be available in the **575V, 5-15 horsepower range** in 2H 2022. With the addition of the Canadian products, Infinitum Electric is delivering the most comprehensive range of power and frame sizes for the North American HVAC market. The IEs Series offers 10 percent more efficiency and IoT capabilities in a package that is 50 percent lighter and smaller, and significantly quieter than traditional motors.

To date, Canadian HVAC applications requiring 575V power have largely relied on suboptimal motor configurations due to a lack of focus on the specific needs of the Canadian market. HVAC applications have therefore used either an EC motor and a transformer to convert power, which adds costs and reduces overall efficiency, or a conventional, lower efficiency AC induction motor and VFD.



This past January marked another major milestone for **Epec, LLC** as it **celebrates 70 years** of delivering quality and reliability in the electronics manufacturing industry. As the oldest printed circuit board company in North America, Epec has proven once again why it is one of the top industry leaders in custom build-to-print electronics.

Based in New Bedford, Mass., Epec has consistently been recognized for its industry leadership, receiving awards from customers, organizations, and publications. In the past two years, Epec also demonstrated that its world-class logistics and supply chain operations continue to deliver for customers even during the most difficult times. Over the past 70 years, the electronics manufacturing industry has changed dramatically. As the industry continues to adapt to evolving demands and technology, Epec is at the forefront of innovation with the expertise and agility to move at the speed of today's businesses.

Ed McMahon, CEO of Epec, commented: ''We are extremely pleased to announce that our company is turning 70 years old. When I purchased Epec back in the early 2000s, I never could have imagined the growth that our team has been able to achieve.''



Steril-Aire, a leader in the development of high-performance indoor air quality (IAQ) and ultraviolet germicidal irradiation (UVGI) technologies, announces the launch of their **Upper-Air Pro+ system**. Available in three models, these units are expertly engineered to quickly disinfect indoor air within population dense areas for airborne pathogens such as influenza, SARS-CoV2, tuberculosis and measles. Recommended for 24/7 use, particularly when an area is occupied, the Upper-Air Pro+ allows for continuous treatment of indoor air.

"Steril-Aire is a proud leader in providing science-based, proven indoor air quality solutions", said Steve Gitkin, Vice President for Steril-Aire. "Our new Upper-Air Pro+ fixtures combine industry-leading UVC output with a streamlined, attractive and highly engineered design. The fixtures are easy to install and are the perfect solution for environments like classrooms, medical facilities, and commercial offices." The Upper-Air Pro+ is factory assembled, tested, and includes the following components:

- Adjustable mounting bracket
- Electrical housing containing easy ON/OFF switch and prewired plug for use with a standard grounded power cord (included)
- Parabolic reflector constructed from specular aluminum; a highly reflective mirror-like material used to maximize ultraviolet output
- Industry-leading output UVC emitter
- Protective baffles block stray UVC light

Steril-Aire launched the "UVC for HVAC" market in 1994. At the time, "Sick building syndrome" was a concern for many building owners and managers. Upon investigation, UVC's germicidal qualities, when applied in HVAC systems, was shown to eliminate pathogens from air and surfaces, including coil fins. ISO certified in both 9001:2015 & 14001:2015, Steril-Aire held multiple pioneering patents throughout the history of the company and developed new and better ways to get the power of UVC directly where it needs to be in sufficient dosage to provide true solutions for the eradication of biological problems. Steril-Aire has always delivered the greatest UVC output in HVAC system conditions and according to the EPA and US Department of Homeland Security testing, generates a 6X disinfection advantage or more over any other UVC offering in the industry, even now almost 30 years after their high-powered emitters were first developed.



Littelfuse, Inc. launches its **SB5000 Industrial Shock Block Ground-Fault Circuit Interrupter** (GFCI) to help protect workers from electrical shock by detecting leakage current, and interrupting the circuit for loads up to 60 A. In addition, the SB5000's advanced ground check protection functionality monitors the ground wire for continuity, from the Shock Block to the load, to interrupt power or prevent energization of equipment if compromised.

The SB5000 Shock Block is suitable for many industries such as food and beverage, commercial kitchens, construction, mining, general manufacturing as well as in places where electrical equipment is being used outdoors or in wet environments.

''More than 90 percent of electrical fatalities among US workers are due to electrical shock, and even minor shock injuries can result in life-altering and debilitating symptoms,'' stated Mark Pollock, global product manager, Littelfuse Industrial Business Unit. ''To help prevent these events, systems should be designed to eliminate the hazards with engineering controls like the Littelfuse SB5000 Shock Block which helps reduce system downtime, lower costs, and most importantly prevent personnel injuries and fatalities.''

In addition to the standard functions such as a 6 mA trip level for Class A and 20 mA for Class C and D devices, the Littelfuse SB5000 Shock Block:

- reduces unnecessary tripping by implementing the inverse time curve defined by UL 943 as well as a DFT filtering algorithm;
- includes NEMA 4X and IP69K enclosure ratings for all food preparation environments;
- whas advanced ground-check functionality with a two-stage Zener termination option meeting CSA M421 which can identify a crushed cable before the equipment is energized.



Fenwal Controls introduced its new **PIM® commercial boiler system**, a combined controller and gas ignition module that can be customized to original equipment manufacturer (OEM) specifications. It enables comprehensive, simultaneous control of ignition, temperature and fan speed across multiple boilers. The Platform Ignition Module (PIM) system is compatible with boilers of any size and most OEMs and includes industry-standard Modbus connectivity to enable seamless communication with existing building management systems (BMS).

The system includes integrated wireless technology to allow better control and support. Fenwal Controls, a leading supplier of gas ignition and temperature control components, is part of Carrier Global Corporation (NYSE: CARR), the leading global provider of healthy, safe, sustainable and intelligent building and cold chain solutions.

Traditional controllers typically require individual factory programming for each model boiler, or on-site configuration. As part of the PIM system, the module is designed to support an entire range of boiler models with just one SKU number. The result is lower installed factory cost and simplified maintenance in the field.

"With most modern installations consisting of multiple boilers, ease of configuration and flexibility is key," said Marc Silverstein, Product Manager, Fenwal Controls. "The PIM system works seamlessly across multiple boilers and with the existing BMS, ensuring maximum comfort and heating efficiency."

For ease of installation, the PIM system supports parallel and primary/secondary piping for several preconfigured piping modes. It can store up to 127 discrete OEM operating programs. A single SKU can be placed in 127 different types of boilers and, when matched with a simple identification card, can run the proper program for each boiler. The user can control up to eight boilers simultaneously through an easy-to-use touchscreen interface with fully integrated capacitive touch functionality and multi-language support.

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Figure 1: Power Analyzer screens are designed to display test setup, digital display of measurements as well as scope presentation of data

Power Analyzers: A Designer's High-Performance Test Equipment Tool Box

BY VITREK

The Power Analyzer puts into a single instrument all the tools needed to study and optimize virtually any power project.

Introduction

The design of any power conversion system requires the measurement of a large range of electrical parameters that could be made using a lab bench full of instruments. The Power Analyzer pulls all of these measurements into a single instrument replacing meters, oscilloscopes, chart recorders, harmonic analyzers and other devices.

This paper will provide a basic overview of the functions and capabilities of high-performance analyzers. Examples of these functions and how to apply them will make use of details provided in the Operator's Manual for Vitrek's Model PA9xx Series of Power Analyzers.

What is a Power Analyzer?

Power Analyzers are a class of electronic instrumentation that combine the precision measurement and recording of a variety of parameters critical in designing and evaluating systems designed to generate, convert and consume electrical energy. Parameters include voltage, current, frequency, harmonics, RFI/EMI, power, efficiency and others. In addition to performing these measurements, Power Analyzers typically include the capabilities of saving setup data, producing reports, communicating via digital means with external devices and other Power Analyzers to perform and archive testing of complex systems. Some Power Analyzers have built-in functions to test equipment for compliance with efficiency and emissions standards.

In short, Power Analyzers are more than a mere collection of measurement and display functions. These instruments provide an integration of those functions into

a cohesive tool required in the design and manufacturing of power electronics equipment.

Power Analyzer Capabilities

By combining the features and functions of a collection of instruments, PAs provide the ability to not only measure a wide range of parameters but also display the information in useful and effective ways, store the test setup information and data acquired and communicate/synchronize the information. Figure 1 presents a sampling of the data that is typically available on a PA screen.

The image on the top displays the real-time data for the AC input of a power conversion device: input power (W, VA and VAR), power factor, voltage (V), current (A) and frequency. The left-hand screen display plots the harmonic content on the output of a converter plus the total harmonic distortion (THD) value. The right-hand screen is an oscilloscope display of the single-phase AC voltage and current of an adjustable-speed drive.

Many other display options are typically available, including 3-phase vector display of voltage and current, historical data, bar graphs of harmonic content and other useful information.

Power Analyzer Applications

By combining the features and functions of a collection of instruments, Power Analyzers provide the ability to not only measure a wide range of parameters, but also display the information in useful and effective ways, store the test setup information and data acquired and communicate/synchronize the information. Applications where PAs are commonly utilized, and the measurements typically made include:

- **AC to DC Power Supplies** - input power factor, inrush current, efficiency, harmonics, EMC emissions/compliance, current, power
- **DC-DC Converters** - power factor, efficiency, harmonics, EMC emissions/compliance, current, power, ripple
- **Motors** - inrush, efficiency, power, frequency, phase diagrams, speed/torque/direction transducers (analog and digital)
- **Adjustable Speed Motor Drives** - efficiency, harmonics, frequency, power, crest factor, compliance
- **LED Power Supplies** - power factor, ripple, power, efficiency
- **Solar Power Systems** - peak power point, voltage, efficiency,
- **Uninterruptible Power Supplies** - power factor, efficiency, output voltage, output frequency, harmonics, phase to phase measurements and phase angles
- **Battery Chargers** - input power factor, efficiency, harmonics, EMC emissions/compliance, current, power, ripple
- **Electric Vehicle Power Systems** - efficiency, power, voltage, charging current
- **Appliances / HVAC Systems** - standby power measurements and testing (for example to EN50564), power factor, efficiency, EMC emissions compliance

Scope capture and history are valuable tools for short term or long-term characterization during design and development. In addition to these product design, development and manufacturing applications, Power Analyzers are also employed in the field to troubleshoot problems and assess performance of systems in operation.

Power Analyzer Configurations

Many basic applications require the use of a single Power Analyzer. Most analyzers provide the capability of making multi-phase measurements. Here in this section, several applications requiring the application of one or more PAs will be described.

Single Analyzer Applications

Power Analyzers are connected between the source and load, as shown in figure 2. All of the measurements described earlier in this article are possible with a single analyzer, with the exception of efficiency which must calculate this value based on measurements of input power and power output.

Dual Analyzer Applications

In applications where both input and output measurements must be conducted simultaneously, it is frequently necessary to utilize two

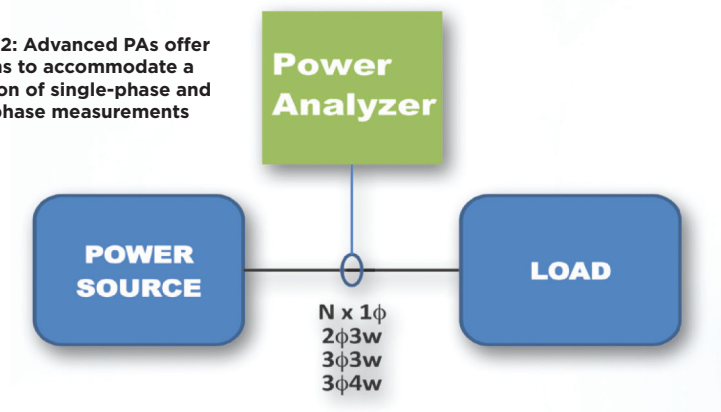


Figure 2: Advanced PAs offer versions to accommodate a selection of single-phase and multi-phase measurements

PAs, as shown in figure 3. (Later in this article, Vitrek's proprietary Virtual Power Analyzer (VPA) will be described that, in many cases can eliminate the need for a second instrument.)

A list of typical applications requiring dual PAs would include the following;

- AC to DC Power Supplies (single or multiple outputs)
- DC to DC Power Supplies (single or multiple outputs)
- DC or fixed frequency AC supplied variable or fixed speed motor drives Power Transformers (single or multi-phase)
- Lighting Ballasts (most types)
- Standby or Backup Power Supplies (AC or DC)
- Photovoltaic Power Generators (DC in; DC or AC out)
- Electric Vehicle Traction Motor / Generator Drive Systems

Triple Analyzer Applications

Complex systems with multiple power conversion stages like these listed would require three synchronized PAs as shown in figure 4.

Examples of electronic systems requiring three PAs to fully characterize performance include:

- Emergency Lighting Ballasts (most types)
- Standby or Backup Power Supplies (AC or DC)
- Solar Systems with Auxiliary Battery Backup

Note that in large systems, e.g., distributed power networks, the input PA can be placed literally miles away from the output PA. In addition, there are very intricate applications, like inductive wireless charging of EV batteries that would require four geographically-distributed PAs.

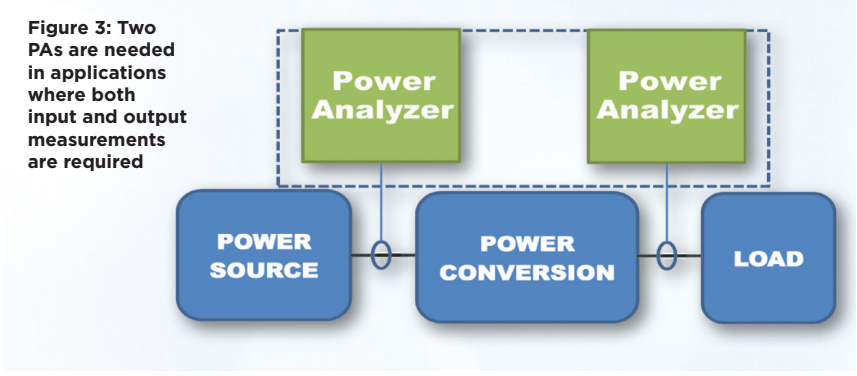


Figure 3: Two PAs are needed in applications where both input and output measurements are required

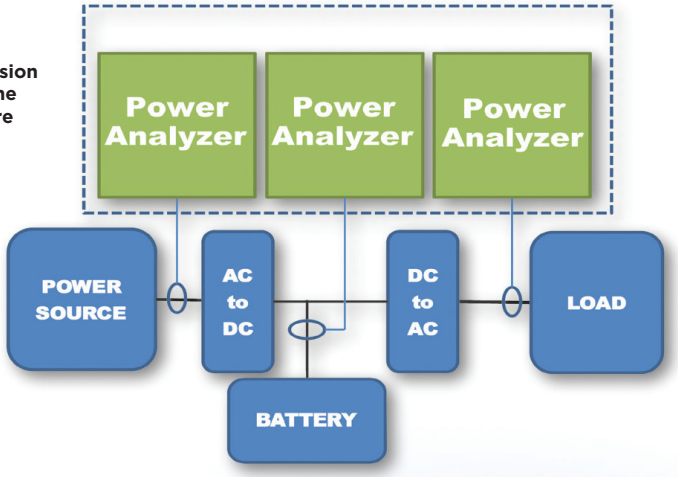


Figure 4: double-conversion systems, like the UPS shown here would require three PAs to completely characterize performance

The Virtual Power Analyzer – A Better Solution

The information presented in this article is intended to provide a basic understanding of the utility and effectiveness of Power Analyzers in the design, development and analysis of power conversion systems. In many cases, the application requires the use of multiple PAs to accomplish the task at hand. While nearly all PAs provide versions that can handle either single phase or multiple phase inputs, only Vitrek provides the ability to integrate separate PAs into the same instrument. Vitrek has taken this concept further by essentially making each channel in the device into an individual PA channel. Channels can be combined into Virtual Power Analyzers (VPAs) enabling a single device in some applications to perform the work of multiple instruments.

Here is a short list of the performance features of Vitrek PA9xx Series, 4-channel PAs:

- Supply frequency measurements DC and 0.01Hz to over 1MHz (W channels) or 100kHz (L, A or S channels) supply frequencies
- N x 1ø can be up to 4 AC or DC supplies
- 2ø3w and 3ø4w measures neutral current from phase currents
- 3ø3w can use either 2 or 3-wattmeter methods
- 2ø3w, 3ø3w (3ch) and 3ø4w measures phase-to-phase voltages in addition to the individual phase voltages
- Wye (3ø4w) and Delta (3ø3w) voltage conversions for 3ø3w and 3ø4w resp.
- Power can flow in either direction, separately integrates power in each

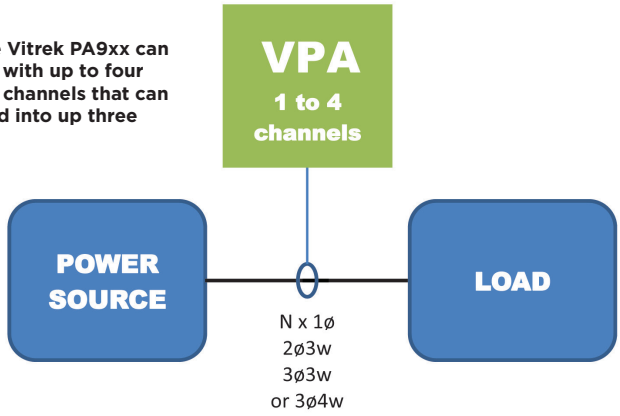


Figure 5: The Vitrek PA9xx can be equipped with up to four independent channels that can be configured into up three separate PAs

direction (per phase and total) as well as the total

• Total power (W, VA, VAR and PF) measured in addition to the individual phases

• Max. hold maintained for voltage, current and power measurements

• Harmonic analysis of every signal up to the 500th harmonic, <435kHz (W channels) or <115kHz (L, A or S channels)

One special feature, worthy of note in this paper, is the built-in compliance test for various industry leading environmental performance standards. These compliance tests are integrated into the PA9xx Series and are selectable from the touch-screen. The test results can also be displayed on the touch-screen with no requirement for PC-based software. This on-display feature significantly improves the user interface and efficiency when performing these critical tests. Engineers and technicians enjoy the flexibility of using the touch-screen at the test station with software available if required. Vitrek PAs' built-in compliance testing support environmental / performance standards including:

• EN60034-2-1:2014 (motor drives)

• EN50564:2011 (standby power)

• EN61000-3-2 and 3-12 and 4-7 (harmonics emissions)

• RTCA DO-160E/F/G (avionics)

• Boeing 787B3-0147

• Airbus ABD0100.1.8 (A380) and ABD0100.1.8.1 (A350)

VPA Application Examples

A few examples of the Vitrek VPA architecture will illustrate the convenience and economy of this approach:

• Power Supplies

AC-DC power supply with a three-phase AC input and a DC output could be analyzed with a single 4-channel PA9xx Power Analyzer. Three channels would be combined as one VPA to measure and record the 3-phase input. The fourth channel would then measure the DC output. All input/output measurements, including efficiency, are contained within one device without any external synchronization.

• EV Drive Systems

The analysis of the performance of an Electric Vehicle drive system can be accomplished by assigning two channels each to the interface between the battery and two channels as a second analyzer between the power converter and the motor. Bi-directional energy flow, efficiency and a full range of performance features can be handled with a single instrument.

• Photo Voltaic (PV) Inverters

The output of the PV cell (DC) can be monitored on one of the four available channels, while the 3 phase AC output (output of the power conditioner inverter and converter) can be monitored using the remaining 3 channels. From this, efficiency studies can be performed using the built in VPA's of the power analyzer.

• Motor Efficiency Calculations

Motor manufacturers and users can easily perform efficiency studies to IEC 60034-2-1:2014 (built in to Vitrek PA) which classifies the levels of motor efficiency.

Important VPA Features

• Oscilloscope Measurements

Many applications require oscilloscope measurements of voltage, current and power. The PA9xx integrated oscilloscope hi-resolution oscilloscope function provides up to 24-bit resolution. Most oscilloscopes only have eight bits of resolution. This means they only have 256 vertical digitizing levels. The PA9xx has 65,536 times better vertical resolution! Typical oscilloscopes are either two or four channels (there are specialized oscilloscopes with more channels). The PA9xx integrated oscilloscope can display up to 12 channels (any six at a time). Any measurement parameter can be plotted as a channel. So, for instance the instrument can display input voltage, current and power and the output voltage, current and power, simultaneously.

• Harmonics

Normal harmonics analyzers measure the harmonics up to 10x or 50x the fundamental frequency. However, some of the new requirements ask for more. The PA9xx Harmonics Analyzer function can measure up to the 500th harmonic of the fundamental! Again, because of the instrument's up to 24-bit digitizing, it performs better than many dedicated spectrum analyzers. This is needed for looking at small signal content in the presence of large

signals.

• Distributed Analyzers

With the PA9xx, up to three separate Power Analyzers can be combined to get up to twelve time-synchronized, distributed channels. For example, channels of one analyzer can be assigned to the input, and channels of another analyzer to the output, enabling measurement of the efficiency of the system, even if the input and output are geographically separated by miles!

• Extended Measurement Capabilities

The PA9xx is also capable of measuring rectified data and signals with crest factors as high as 100. The instrument can also measure load impedance - series inductance and resistance; parallel capacitance and resistance, energy consumption (KWH), average power (W), and calculate energy bought or sold.

• Datalogging

The PA9xx datalogger function timebase rescales automatically over the length of the test. So, for a 1-hour test, the display will be for 24 hours. For a ten-day test, it will display over ten days. However, the data logged for any specific moment over the test period can be retrieved as well as the min and max peaks between datapoints. Datalogging can be performed for up to 16 different measured parameters. The time base can scale up to 584.5 million years (collection is automatically stopped after this time has elapsed. This is not fully tested at the time of writing!). Any measurable parameter can be displayed on the screen as a trace and logged data can be saved to an external USB drive.

• Reporting

The PA9xx provides the capabilities to clearly document and produce reports of the results of the tests performed. As with other Power Analyzers, data can be exported via Ethernet or RS-232. The PA9xx also features front-panel USB drive access. The USB drive can be used to save and recall configurations, harmonic limits, measurements, spectrum analyzer data, scope data, cycle data, history data and harmonics data. Easiest of all, screen shots can be captured of anything data selected, such as this:

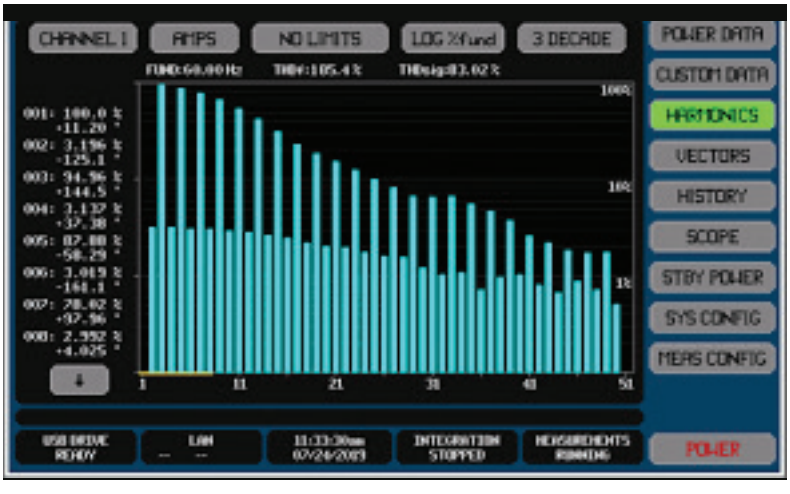


Figure 6: Data selected for display on the PA9xx can be easily exported via the front-panel USB access port.

Conclusion

The Power Analyzer combines into a single instrument that functions and features of several benchtop instruments. It truly is the electronic design engineer's instrumentation toolbox. And none is easier to use or more economical than the Vitrek PA9xx Series. The PA9xx's Virtual Power Analyzer simplifies setup and synchronization of input and output test data, enabling the ability to perform intricate and accurate tests with few instruments. The following is a useful checklist that may be helpful:

• Simple setup and operation via a touchscreen display

• High-resolution digital display

• Supply frequency measurements DC and 0.01Hz to over 1MHz supply frequencies

• Multiple accuracies and frequencies based on your specific application

• Single phase and multi-phase inputs (including all common types)

• VPA (Virtual Power Analyzer) features extending the testing capabilities of the Power Analyzer

• Input voltages up to 600VAC

• Bi-Directional power flow (per phase and total)

• Total power (W, VA, VAR and PF) measured in addition to the individual phases

• Max. hold maintained for voltage, current and power measurements

• Harmonic analysis of every signal up to the 500th harmonic

• Datalogging capabilities with scalable timebase

• Report generation capabilities

• Built-in programming to testing to selected safety and emission standards.

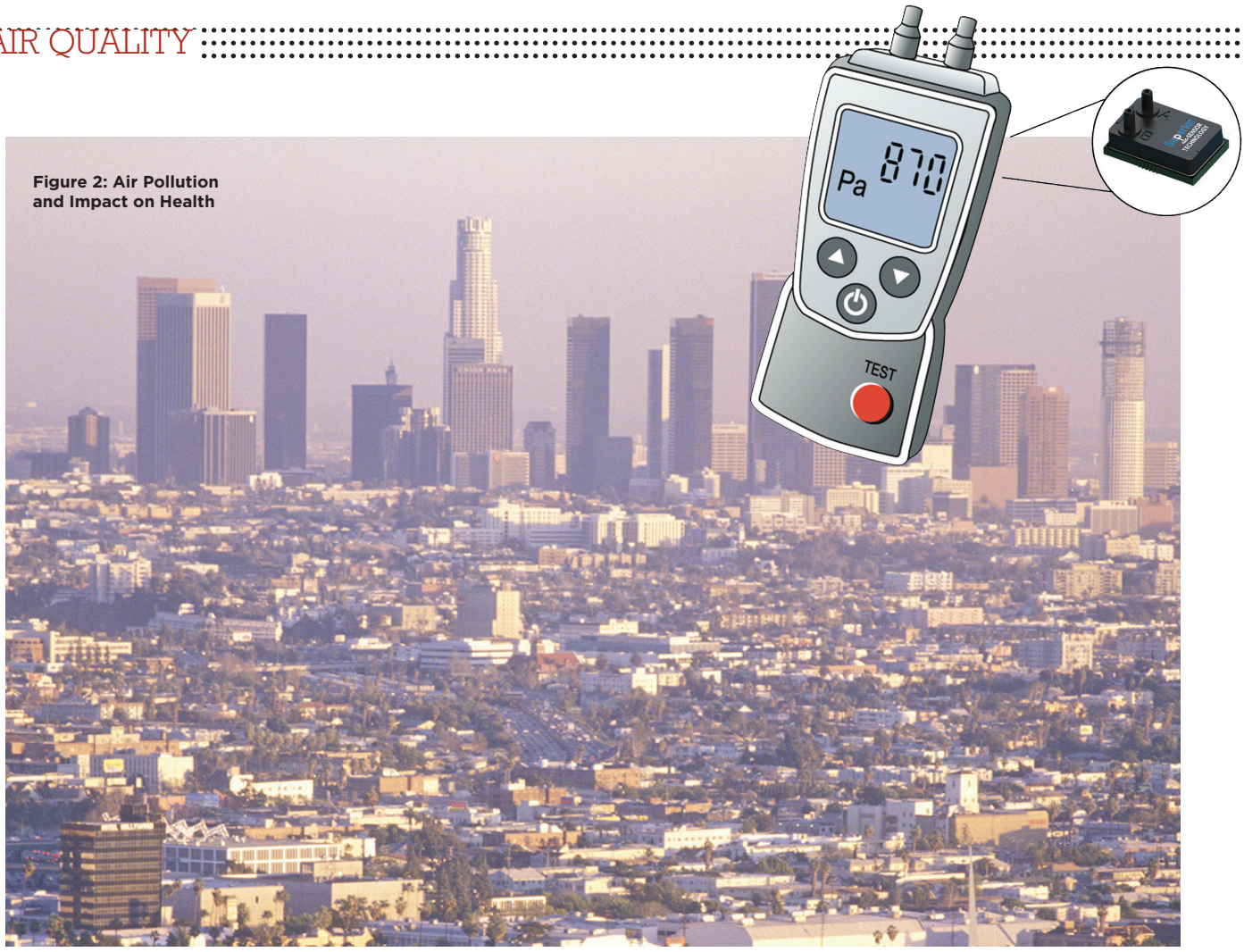


Figure 2: Air Pollution and Impact on Health

Ensuring the Most Accurate Air Quality Readings

BY SUPERIOR SENSOR TECHNOLOGY

Air quality is a serious topic these days. From airborne viruses to pollution, allergens and gas leaks, accurately ensuring the safety of the air we breathe is paramount. To do so, organizations use air quality measurement devices to measure particles and other contaminants in the air, like the one shown in Figure 1.

Air quality embodies a host of applications including:

1) Air filtration systems that monitor not just the flow rate of air, but the quality as well

2) Carbon monoxide detectors to ensure carbon monoxide levels do not exceed safety levels

3) Fume hood monitors to limit exposure to hazardous or toxic fumes, vapors or dust

4) Clean room environments to ensure dust or other particles do not contaminate the laboratory or manufacturing facility



Figure 1: Air Quality Measuring Device from Particles Plus

5) Radon detectors to determine levels of radon in the environment

6) Air purifiers to ensure the air flow meets the air quality requirements

7) Smoke detectors to help provide early detection of a potential fire

8) Carbon dioxide detectors to indicate levels of carbon dioxide in the air

9) Smog detectors to measure pollution coming from an automobile exhaust

10) Outdoor air monitoring to measure levels of pollutants in the air

The Role of Differential Pressure Sensors in Measuring Air Quality

Differential pressure sensors measure the difference in air flow and play a critical role in measuring air quality where determining exposure to potential contaminants is important. There are many airborne particles

that if they exceed a certain amount can be hazardous: airborne viruses, carbon monoxide, radiation, toxic fumes, etc. – the number of potential contaminants is endless.

The system works as follows: through a flow element, such as a Venturi, the differential pressure sensor measures air flow between its two ports. This enables the air monitoring system to calculate the particle density in the air for which it is measuring. Based on the result, the system may generate an alarm or other warning if the density exceeds a predetermined value.

However, as with most electromechanical devices differential pressure sensors are sensitive to many external factors including noise, humidity, temperature and physical positioning. Differential pressure sensors that reduce the impact of external factors will provide the most accurate differential readings for computed airflows and thus air quality measurements.

Better Performance & Lower System Cost

Superior Sensors' proprietary NimbleSenseTM architecture is the industry's first System-in-a-Sensor integrated platform. Incorporating a highly differentiated advanced pressure sensing system with the ability to integrate optional building blocks, enables us to combine the highest accuracy and reliability with lower overall system cost. For air quality applications, we have developed our HV Series of differential pressure sensors.

Highest Levels of Accuracy

The HV Series was designed to provide the highest levels of accuracy and greatest reliability for air quality and other HVAC applications. The HV Series provides accuracy within 0.10% of the selected pressure range with long-term stability as low as 0.10% and Total Error Band (TEB) within 0.15% FSS. These market leading figures ensure the highest accuracy when monitoring air quality levels.

Lowest Noise Floor

The HV Series offers our integrated advanced digital filtering technology – a multi-order filter that utilizes advanced filtering capabilities on the front-end of the sub-system to eliminate critical noise created by fans, blowers or other dry air/gas sources prior to reaching the pressure sensor. This reduces system noise levels by 10x or more, and allows the sensor to make extremely accurate readings.

Integrated Closed Loop Control

The NimbleSense architecture's integrated closed loop control can be applied to improve the reliability and speed/responsiveness of the air quality monitoring device. This capability can significantly reduce loop delays and ensures accurate readings by directly controlling motors, valves and actuators. This integrated capability also simplifies product design, reduces system power/heat and provides an improvement in accuracy.

Multi-Range™ Technology

One of the most innovative NimbleSense architecture features found in all of our differential pressure sensors is our unique Multi-Range technology that allows one sensor to replace several different sensors. On the HV Series, Multi-Range can support up to 8 different pressure ranges with each pressure range factory calibrated and optimized to ensure no degredation in total error band, accuracy or stability regardless of the range selected. Figure 3 shows the difference between a typical

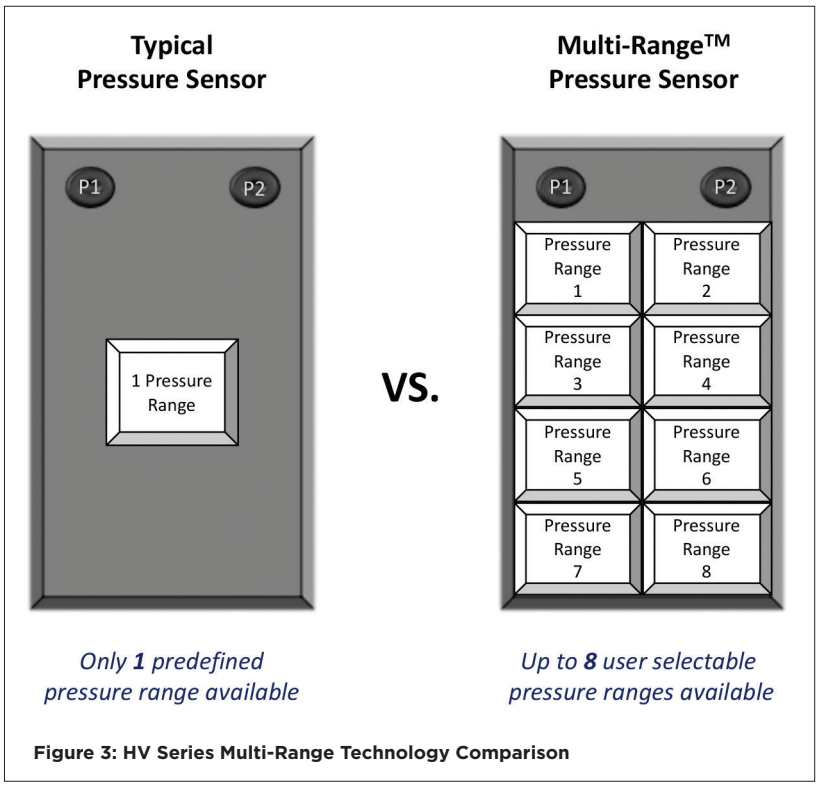


Figure 3: HV Series Multi-Range Technology Comparison

differential pressure sensor and the Superior Sensor's HV Series.

With Multi-Range, pressure ranges can be changed 'on the fly' so that one device in the field can be used to serve multiple purposes. Multi-Range also enables manufacturers to bring product variants to market quickly and reduces inventory costs and product obsolescence since only one SKU needs to be stocked.

Position Insensitivity

Extremely beneficial for eliminating concerns with sensor orientation and ideal for handheld or portable air quality measuring devices, Superior's unique dual-die implementation with the HV210 maintains consistent and highly accurate readings regardless of physical orientation or movement of the air quality measuring device. Rated with a positional sensitivity to within 0.25 Pa, the HV210 is an industry leaders with respect to position insensitivy.

Reduction in System Costs

By utilizing a System-in-a-Sensor approach where the sensor module integrates many advanced functions and multiple pressures in one device, Superior Sensors is simplifying product design and helping bring down system costs. In addition to the Multi-Range cost savings mentioned above, the integrated closed loop control and advanced digital filtering provide further system cost savings. With these capabilities directly in the sensor module, there is no longer a need to externally design these functions with discrete components. This reduces BOM cost and PCB footprint, increases reliability and speeds time to market.

Conclusion

There is no question behind the importance of air quality measurement devices. Whether tracking internal or external air quality, the need to accurately detect dust particles, chemicals, viruses and other pollutants will continue to grow. With more air quality devices being deployed, ensuring their reliability is just as important. Removing uneccesary components reduces the number of field failures. Further, allowing the air quality devices to be configured 'on the fly' maximizes flexibility and expands the potential uses of the system.

The NimbleSense architecture has several building blocks (see Figure 4) that are customized specifically for air quality applications:

- Multi-Range
- Closed Loop Control
- Advanced Digital Filtering

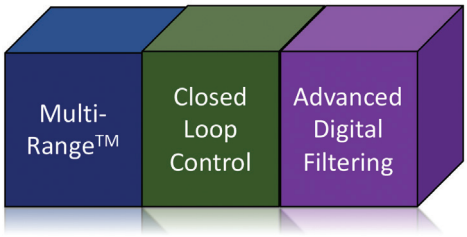


Figure 4: NimbleSense Building Blocks for Air Quality Applications

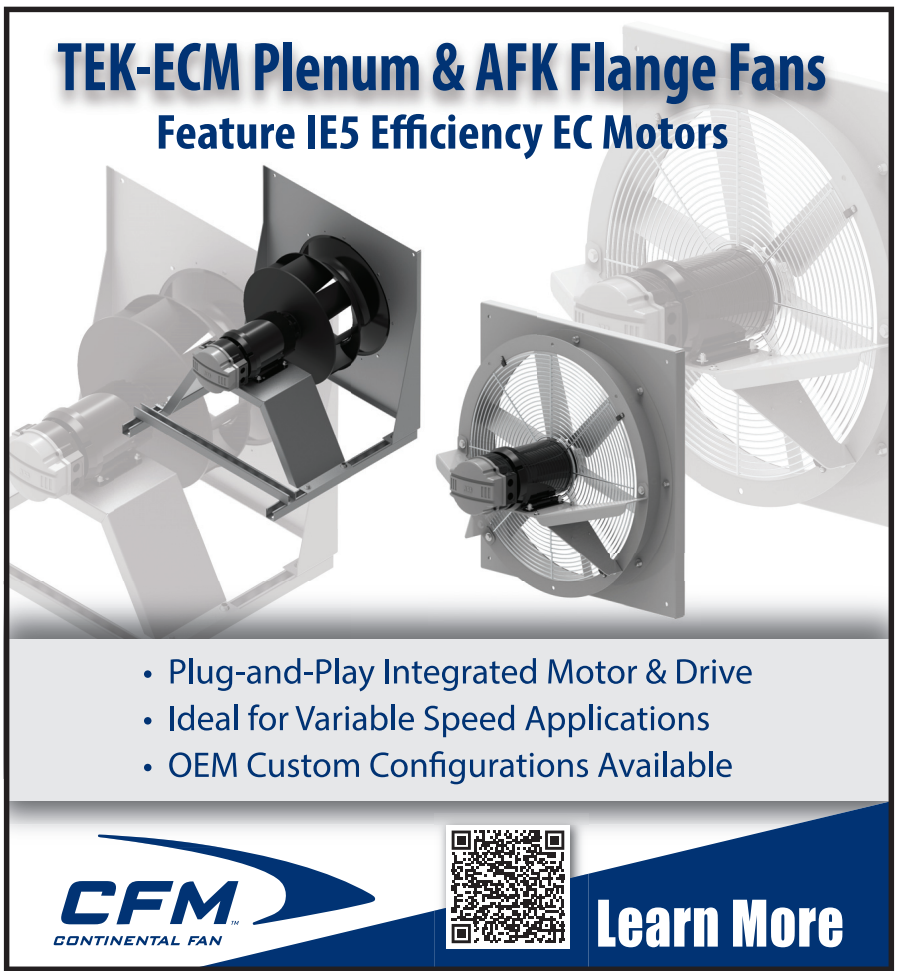
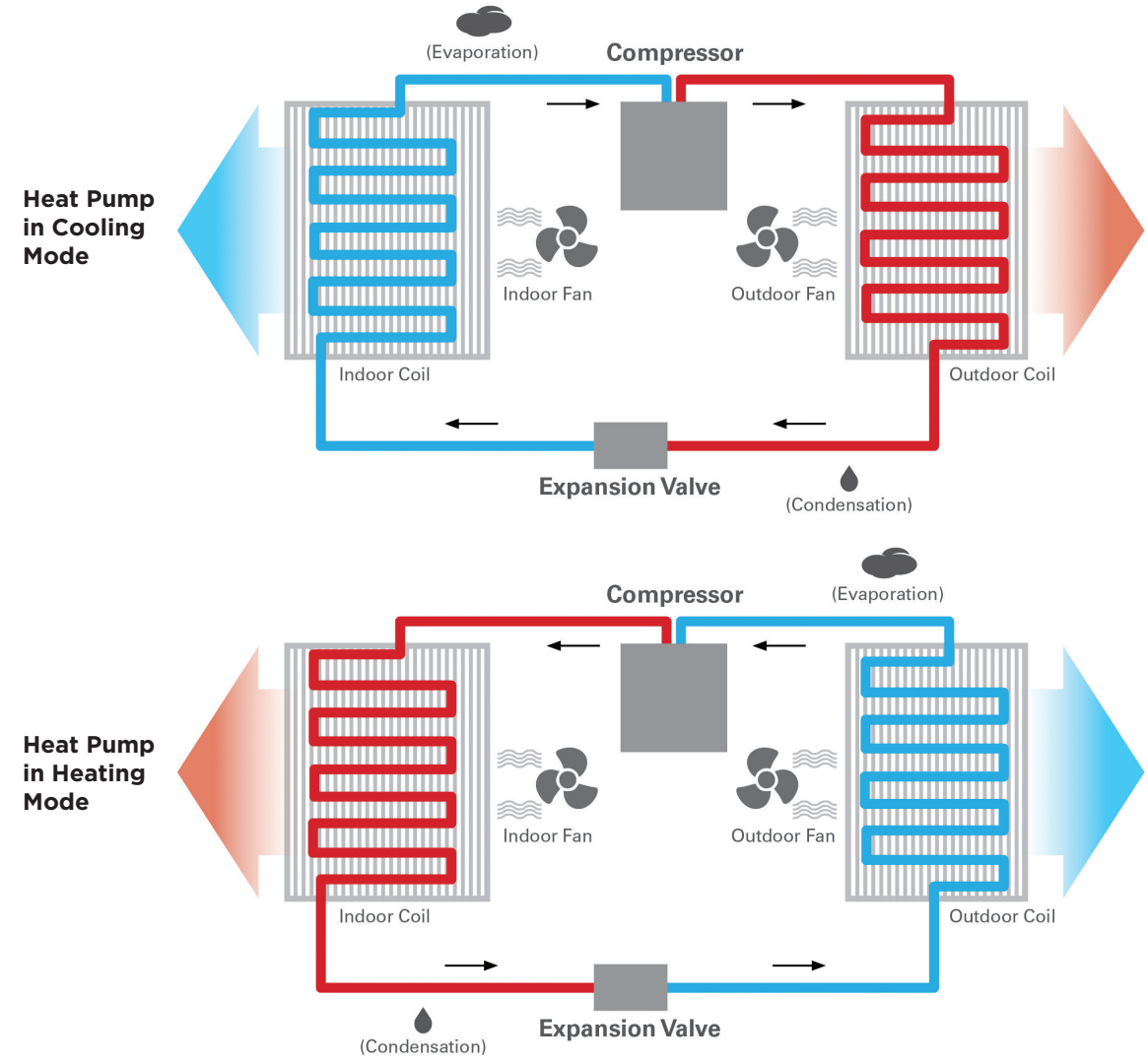


Figure 1: Simplified diagram of a heat pump



How to make your heat pump designs more reliable, safer, and with higher efficiency

BY RYAN SHEAHEN

Heat pumps perform both heating and air conditioning and are all-electric systems. Unlike a fossil fuel heating system, heat pumps do not convert combustible fuel into heat energy. Thus, heat pumps are another tool in the global effort to reduce carbon dioxide emissions and minimize the potentially catastrophic effects of climate change on the planet. Over 80 countries have endorsed the Net-Zero Emissions (NZE) initiative, which requires a 50% reduction in greenhouse gas emissions by 2030 and net-zero emissions by 2050. Heat pump heating, ventilating, and air conditioning HVAC) systems are a critical part of the emission reduction strategy. Governments encourage growth in heat pump usage by offering incentives, such as rebates on purchases. Also contributing to the growth are advances in inverter-driven

motor technology and more efficient electronics, enabling the development of more efficient heat pumps. The improved efficiency allows heat pump use in a broader range of climates. As a result, the industry expects global annual heat pump installations to increase from 10M units in 2020 to 15M units in 2025, growing at an 8.5% CAGR.

Design teams need to ensure their heat pumps are reliable, safe, and efficient. The electromechanical and electronic systems require protection from hazards such as AC mains-induced overloads and transients and electrostatic discharge (ESD). The power components need protection from the destructive effects of overheating. Using the appropriate topologies and electronic components will contribute to optimized heat pump efficiency. This article will assist designers in achieving reliable, safe, and efficient heat pump designs.

Overview of heat pump operation

There are three types of heat pumps, classified by power source: water-powered, geothermal, and air source. The most common heat pump is the air source heat pump which will be the focus of this article. The air source heat pump is an all-electric HVAC system that moves heat; and, unlike a fossil fuel heating system, does not convert fuel into heat energy. The elimination of fuel conversion enables a heat pump to be more efficient than a fossil fuel HVAC system, and a heat pump does not emit any CO2. Heat pumps are reversible evaporator-condenser systems with two fan motors. As a result, heat pumps are both heating and air conditioning systems. Heat pumps consist of an outdoor fan and coil unit and an indoor fan and coil unit. The direction of refrigerant flow

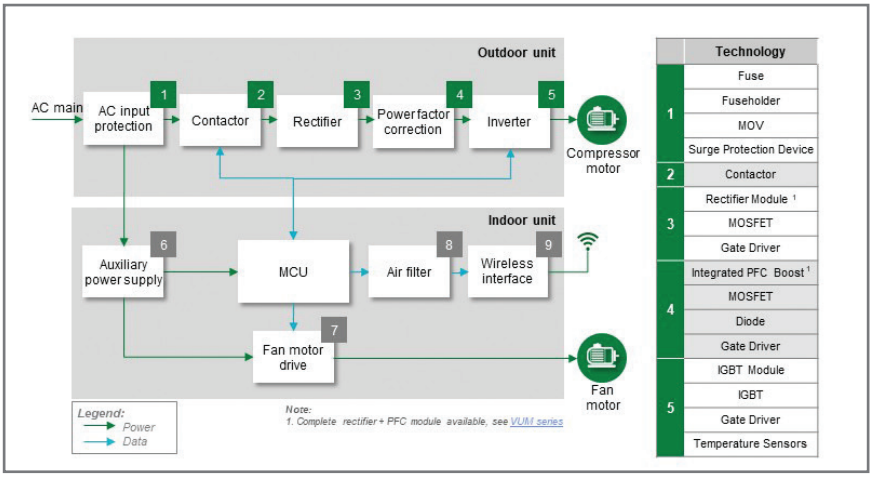


Figure 3: Block diagrams of a heat pump outdoor unit and the indoor unit. The adjacent table highlights the outdoor unit's recommended protection, control, and sensing components.

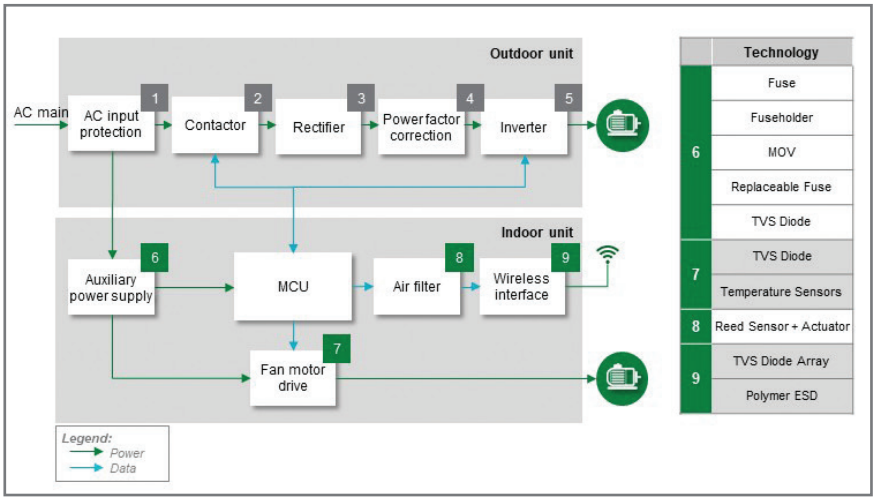


Figure 4: Block diagrams of a heat pump outdoor unit and the indoor unit. The adjacent table highlights the indoor unit's recommended protection, control, and sensing components.

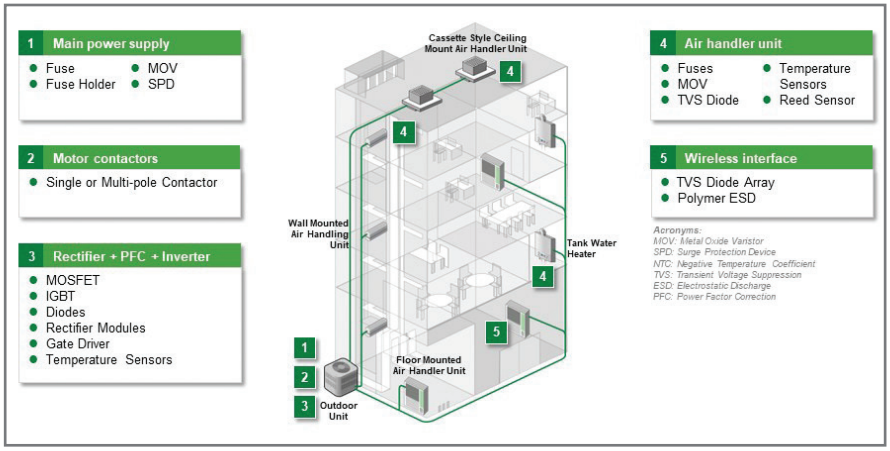


Figure 2: Example of heat pump HVAC and water heater systems in a commercial building. The text blocks around the diagram highlight the main sub-systems of the heat pump and the recommended protection, control, and sensing components for each sub-system.

determines whether the heat pump is heating or cooling inside air. Figure 1 shows the two operating modes of a heat pump.

Sub-systems of a heat pump and the recommended components for protection, control, and sensing

Figure 2 shows a modern heat pump performing as an HVAC system and as a tank water heater for hot water. The diagram includes recommended protection, control, and sensing components for the major sub-systems of the heat pump.

Figures 3 and 4 show block diagrams of the outdoor compressor and indoor air-handling units' heat pump electronics. The table to the right of these diagrams list the recommended protection, control, and sensing technologies. These components provide robust protection of the circuit blocks from current overloads, high voltage transients, and ESD. Some components minimize power consumption to maximize efficiency, while others provide sensing for safety.

Protection, efficiency, and safety for the outdoor unit

AC Input Protection circuit

The AC Input Protection block connects directly to the AC power line and is subject to hazards such as current overloads and voltage transients that propagate on the AC power line. Load faults on the power line can lead to large surges of current. At the input of the AC Input Protection block, use a fast-acting fuse to prevent a current overload from entering the outdoor unit circuitry. Consider these important fuse requirements:

- A current interrupting rating over 10 kA
- A low internal resistance below 100 mΩ to minimize power loss
- Shock-resistant and vibration-resistant construction
- An Underwriters Lab (UL) recognized component compliant with UL standard 248-14 and International Electrotechnical Commission (IEC) standard 60127-1.

Ensure that users can easily replace the fuse after it has interrupted a current overload. Choose a fuseholder that allows easy fuse installation and replacement. Select a fuseholder with a minimum current rating of at least the fuse's rating. Also, select a fuseholder compliant with UL and IEC standards.

Transients induced from lightning and voltage surges from activation and de-activation of high power-consuming devices can cause high voltage transients on an AC power line. Use a metal oxide varistor (MOV) to absorb transients to prevent them from reaching downstream circuitry. Select a MOV with:

- A transient clamping voltage that will prevent damage to downstream circuitry
- Capacity to absorb a few 100 J of transient energy
- An MOV that can withstand kV levels and absorb kA current pulses in compliance with IEC standard 60335-1.

Designers can utilize a surge protection device (SPD) as an alternative to a MOV. SPDs offer a higher level of protection by absorbing up to 50 kA of surge current from a voltage transient that can be as large as 3 kV. The SPD offers a status indicator to allow monitoring of its protection capability. The status indicator informs the control electronics whether a transient strike has damaged the SPD. The SPD trades off a higher level of protection and status monitoring than the smaller size and lower cost of a MOV.

Contactor circuit

Use a contactor to safely control the power to the outdoor fan and compressor motor. Make sure that the contactor has a sufficient current rating to drive the full power requirement of the motor. Consider a contactor with long-life electrical contacts. Look for a contactor with at least a 2 kV dielectric strength between contacts and between contacts and coil material.

Rectifier Circuit

The Rectifier Circuit performs the AC-DC conversion. Investigate using, for rectification, MOSFETs with:

- Fast switching times to reduce switching losses
- Low gate capacitance to minimize gate charge time
- Small Rds(on) to reduce on-state power loss and contribute substantially to reducing power consumption.

Ensure efficient control of the MOSFETs with a gate driver integrated circuit. Ensure that the gate driver can source and sink sufficient current for the selected MOSFETs and look for gate drivers that have a high dv/dt rating for fast switching of the MOSFETs.

As an alternative to discrete MOSFETs, consider rectifier modules. Look for modules with low forward voltage and low reverse leakage current. The fully integrated rectifier modules contribute to a reduced component count.

Power Factor Correction circuit

The Power Factor Correction Block minimizes the power drawn from the AC line by making the heat pump circuitry look as resistive as possible to minimize apparent power and maximize real power.

As an alternative to individual MOSFETs or low forward voltage diodes, consider a MOSFET-series diode integrated PFC boost assembly, reducing component count and

saving printed circuit board space. The series diodes support enhanced dynamic operation for high-frequency operation, maximum efficiency, and fast switching.

Inverter circuit

Avoid damage due to overheating conditions. Use thermistor probes to monitor the temperatures of the motor windings, the refrigerant lines, and power semiconductors. Thermistors offer fast response and a small form factor. Select hermetically sealed thermistors for high reliability.

Investigate power IGBTs or IGBT modules to drive the compressor. These transistors have both excellent thermal characteristics and an ultra-low packaging profile. Like the power MOSFETs, gate driver modules conveniently control IGBTs.

Protection, efficiency, and safety for the indoor unit

Auxiliary Power Supply circuit

The Auxiliary Power Supply powers the control electronics and the DC fan motor, pushing conditioned air into the residential or commercial space. In addition to its primary function, this supply must capture and absorb any portions of overloads and transients propagated through the outdoor unit's AC Input Protection block. Use a fast-acting fuse and a MOV, as recommended for the AC Input Protection block. In addition, protect the sensitive downstream integrated circuits (ICs) with a transient voltage suppressor (TVS) diode. TVS diodes have these benefits for secondary transient protection:

- Ultra-fast, ps, response to a transient
- Low clamping voltages to protect sensitive electronic components
- Uni-directional or bi-directional configurations.

Look for a TVS diode that can absorb a minimum of a few hundred Watts of transient power.

Fan Motor Drive

As with the outdoor unit, use thermistor temperature sensors to prevent overheating of the DC fan motor coils, refrigerant lines, and the power semiconductors. In addition, protect the motor drive circuit and the motor from transients with a TVS diode.

Air Filter circuit

Ensure the air filter is properly positioned to remove particulates from the air supply. Consider a reed position sensor and a magnetic actuator to ensure the air filter is fully covering the air entrance duct. Look for hermetically sealed, magnetically operated contacts that require no standby power. Select the needed sensitivity for the design requirements.

Wireless Interface circuit

The Wireless Interface communicates system status and enables indoor temperature control using smartphones or notepad computers. The Wireless Interface circuit block is in contact with the external environment and is subject to ESD strikes. Use TVS diodes to protect the sensitive ICs. Investigate bi-directional TVS diodes that can safely absorb ESD strikes above 10 kV to protect against damage caused by human contact and through-the-air strikes. Look for a TVS diode with low capacitance below 1 pF to avoid corruption of transmission and reception.

In addition, protect the data lines from ESD with polymer ESD components. Polymer ESD components can provide a minimum of 8 kV of protection and minimal disturbance to signals with capacitances as low as 0.25 pF.

Ensure robust, efficient, and safe heat pump operation with wise protection, control, and sensing

A robust, efficient, and safe heat pump design does not require many components. However, the design project must have documented circuit protection, efficiency, and safety goals. Leaving these objectives as afterthoughts will result in additional re-design time and higher development costs. Application engineering assistance is available. Designers can utilize a manufacturer's expertise to save valuable design time. The application engineers can help with:

- Cost-effective component selection
- Guidance on meeting the required safety standards
- Pre-compliance testing (if the manufacturer offers this) to prepare designers for product certification testing.

Designers who achieve robustness, efficiency, and safety goals will have a substantial competitive advantage.

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Efficiency and Loss Mapping of AC Motors Using GEN 3i Data Recorder

BY RADU BOJOI AND ERIC ARMANDO (HBK)

Recently electrical machines have become an important topic in many industries including power generation, heating/cooling, transportation and home appliances. With increases in efficiency standards and the increase in battery powered devices, the motor efficiency has become an important topic. This has only been amplified recently by the increased controllability of motors by inverters. Motors offer a highly controllable, efficient, and power dense solution to many of today's needs. This shift to electrify all aspects of life has all resulted in the development of many research groups focused on increasing the efficiency of electric motors.

A proper motor control must be implemented in order to maximize efficiency. Often the motor control will operate the machine at the most efficient point for a given power requirement. For this to be possible the machine characteristics must be properly known. Creating a motor efficiency map is the best way of doing this. It involves operating the machine through all possible torque and speed points that the machine would operate in.

This paper describes an automated procedure to obtain the efficiency and loss mapping of AC motors using the HBM Gen3i data recorder.

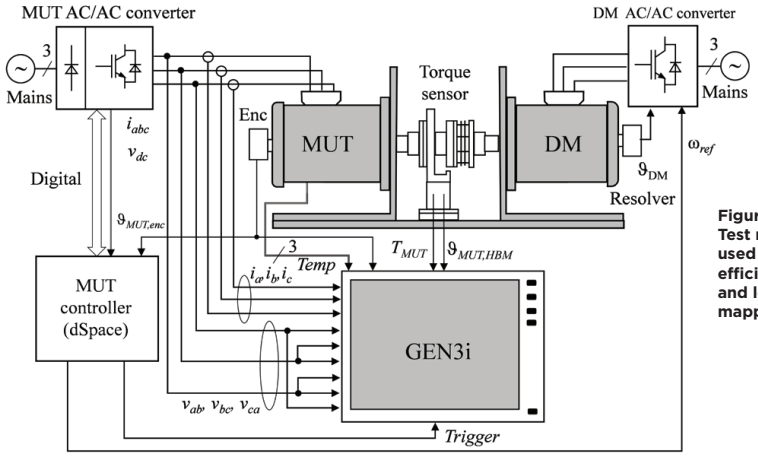


Figure 1: Test rig used for efficiency and loss mapping

The Test Rig

The test rig used for efficiency and loss mapping is shown in Fig.1. The test rig consists of the following main elements:

- Motor under Test (MUT) is an Internal Permanent Magnets (IPM) motor
- The motor controller is a dSpace board with a dedicated analog/digital interface
- The Driving Motor (DM) is a speed-controlled Permanent Magnet (PM) motor fed by a bi-directional converter whose speed reference is provided by the dSpace board using an analog dSpace DAC (digital-to-analog converter) output. Another solution is to use a CAN or RS422 interface, depending also of the communication capability of the converter that supplies the DM



Figure 2: T40 torque sensor for torque measurement

- The torque is measured with the high accuracy HBK T40 torque sensor (Fig. 2) that provides the shaft torque and also the shaft position with a resolution of 1024 pulses/rev (encoder type outputs). The torque sensor is mounted as a mechanical coupler between the MUT shaft and the DM shaft. The data are transmitted to the measurement system by means of a rotating transformer.
- The phase currents are measured with high accuracy, external LEM sensors (Fig. 3) that are fed by a current sensor box that manages the current sensors and generates the outputs that are acquired by the HBK data recorder with the high-speed acquisition channels with a sampling rate of 2Msamples/s. The voltage drops on the LEM shunts are sent to the Gen3i using BNC cables.
- The MUT line-to-line voltages are directly measured by the Gen3i recorder using the high-voltage/high-speed acquisition channels with a sampling rate of 2Msamples/s. In this way, the acquired voltages are the real PWM pulses that are applied to the machine.
- Besides the rotor position provided by the T40 torque sensor, the Gen3i measures also the rotor position using an incremental encoder that is also employed by the motor controller (as shown in Fig. 1). An external splitter card receives the encoder pulses from the encoder and sends them to the motor controller and to the Gen3i with galvanic insulation.
- The motor temperature is

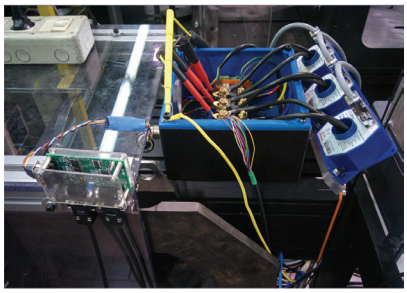


Figure 3a: View of the current sensors for MUT current sensing

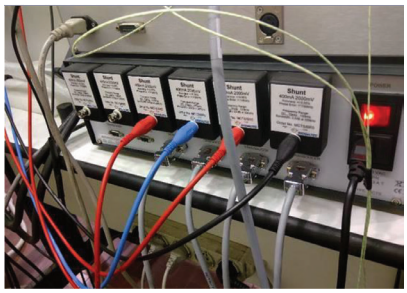


Figure 3b: Rear of the current sensors box



Figure 4a: Programmable isolation amplifiers for temperature measurement

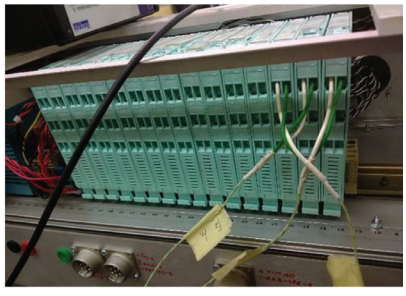


Figure 4b: Programmable isolation amplifiers for temperature measurement

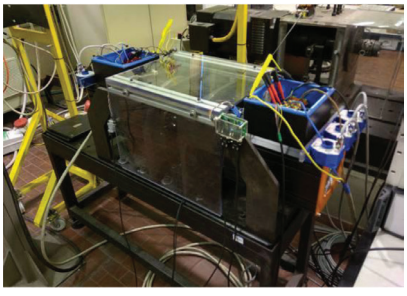


Figure 5: View of the MUT (right) and DM (left)

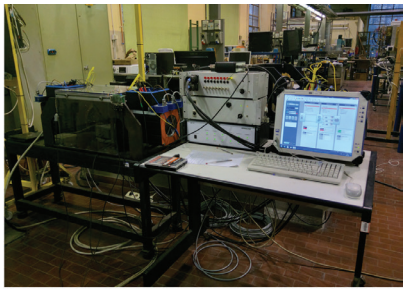


Figure 6: General view of the entire test rig, including the HBK Gen3i data recorder

measured by means of three thermocouples. The thermocouples are read by programmable isolation amplifiers (Fig. 4) whose outputs are provided to a low speed acquisition card of Gen3i.

Efficiency and Loss Mapping Identification Procedure

The idea is to sweep the entire torque-speed plane by creating a mesh of reference operating points that are shown in Fig. 7.

The speed is changed between a minimum value (ωmin) and a maximum value (ωmax). The speed range (ωmax-ωmin) is divided into equal intervals of length Δω that is properly chosen to get a reasonable number of points n (10 to 20). For each speed, the torque is changed between a minimum value (Tmin) and a maximum value (Tmax) with steps of ΔT that is properly chosen to get a reasonable number of points m (10 to 20). As a result, the mesh in the torque-speed plane contains N = n x m points.

The DM is speed controlled and provides the speed for one operating point, while MUT is torque controlled. For each operating speed, the torque is changed with steps of ΔT between Tmin and Tmax, as shown in Fig. 8.

As shown in Fig. 8, one operating point lasts 3 seconds. The motor controller generates a TTL-compatible trigger signal for the HBK data recorder that must store data for 1 second when a rising-edge trigger is detected. The entire procedure lasts about 10 to 20 minutes, according to the chosen number of operating points.

Computations after the Test

Once the test is finished, the Gen3i stores a big data file that can be easily split in N data files, where one file corresponds to one trigger, i.e. one operating point in the torque-speed plane. For each operating point, the Gen3i performs the following computations:

Input electrical power

(1) $P_e = \frac{3}{2} \cdot \frac{1}{T} \int_0^T (v_\alpha \cdot i_\alpha + v_\beta \cdot i_\beta)\, dt (W)$

where the vαβ and iαβ are the voltage and current (α,β) components in stationary reference frame, T is the electrical cycle (period) obtained from the electrical angle.

It must be mentioned here that no filters are applied to the acquired voltage and currents.

Copper (Joule) losses

(2) $P_j = R_{s,avg} \frac{1}{T} \int_0^T (i_a^2 + i_b^2 + i_c^2)\, dt (W)$

The average stator resistance Rs,avg is calculated as

(3) $R_{s,avg} = R_{s,base} \cdot \frac{\Theta_{avg} + 234.5}{\Theta_{base} + 234.5} (\Omega)$

where Rs,base (Ω) is the stator resistance at base temperature (as example, θbase=20 °C) and is the average stator temperature computed as the mean value of the k measured stator temperatures.

The average resistance can be corrected to take into account the skin effects.

Mechanical shaft power

(4) $P_m = T_m \cdot \omega_m (W)$

Where Tm is the measured torque and the ωm is the measured speed.

Iron and mechanical losses

(5) $P_{FeMec} = P_e - P_m - P_j$

Iron loss

(6) $P_{Fe} = P_{FeMec} - P_{Mec}$

where PMec are the mechanical losses that are speed dependent and that must be known in advance.

To avoid any influence of the torque ripple generated by both DM and MUT (with consequences on the speed), all the power values are saved as mean values calculated over a time interval containing a multiple number of mechanical revolutions.

Torque corresponding to the iron loss and to the total loss (iron + mechanical)

(7) $T_{Fe} = \frac{P_{Fe}}{\omega_m} \qquad T_{FeMec} = \frac{P_{FeMec}}{\omega_m}$

The torque calculated with (7) should be the difference between the estimated torque (by the motor controller) and the real shaft torque. The torque values calculated with (7) are provided by the Gen3i as average values over an integer number of mechanical revolutions.

MUT efficiency and inverter efficiency

(8) $\eta_{MUT}(\%) = \frac{P_m}{P_e} \cdot 100$

The inverter efficiency can be

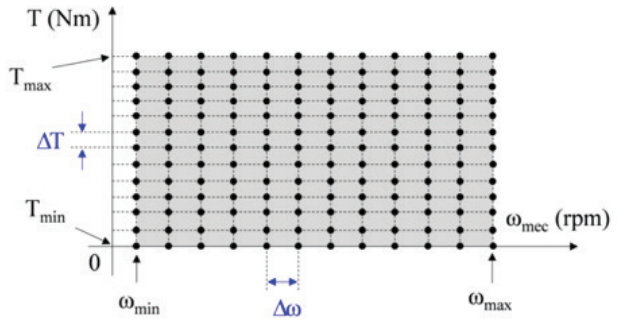


Figure 7: Mesh of operating points in the MUT torque-speed operating plane

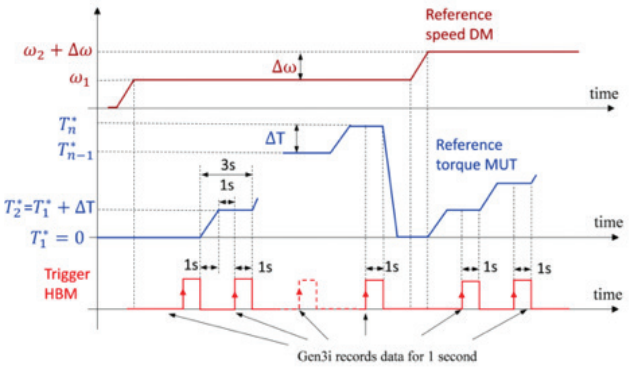


Figure 8: Generation of the DM reference speed and the MUT reference torque along with the trigger for HBK

obtained only if the DC link voltage and the DC link current are measured. In this case, the inverter efficiency will be

$$\eta_{inv}(\%) = \frac{P_e}{P_{dk}} \cdot 100 \quad (9)$$

where $P_{dc} = i_{dc} \cdot v_{dc}$ is the input inverter power that must be averaged for eliminate any ripple in the DC link voltage and current.

Besides the efficiency and loss mapping, the Gen3i calculates and saves the following quantities that are extremely useful for the analysis of the MUT operation:

(A) (d,q) rotor frame flux linkages

The flux linkages are computed first in stationary (a,b) frame as time integral of the back-emf voltages:

$$\lambda_\alpha = \int (v_\alpha - R_{s,avg} \cdot i_\alpha) dt - offset_\lambda_\alpha$$
$$\lambda_\beta = \int (v_\beta - R_{s,avg} \cdot i_\beta) dt - offset_\lambda_\beta \quad (10)$$

An offset correction is necessary for each electrical period (cycle) to avoid the drifting of the computed flux linkage components. Once the (a,b) components are calculated, the (d,q) components are easily obtained with the rotational transformations; the magnitude of the flux linkage is also calculated.

$$\lambda_d = \lambda_\alpha \cdot \cos\vartheta_e + \lambda_\beta \cdot \sin\vartheta_e$$
$$\lambda_q = -\lambda_\alpha \cdot \sin\vartheta_e + \lambda_\beta \cdot \cos\vartheta_e \quad , \lambda = \sqrt{\lambda_\alpha^2 + \lambda_\beta^2} \quad (11)$$

where $\vartheta_e = p \cdot \vartheta_m + offset_{\vartheta e}$ is the electrical position that is calculated from the measured mechanical position, the pole-pairs number and an offset that must be known.

Since the stator flux linkage components are calculated using the real motor voltage and a very good stator resistance, it is assumed that the precision of this computation is very good. In this case, the trajectory of the stator flux vector in the (d,q) plane can be obtained with very good precision and can be compared with the results coming from the magnetic model.

(B) (d,q) stator currents and voltages

The (d,q) rotor frame voltage and current components are calculated from the (α,β) components using the direct rotational transformation (8) that is used also for the fluxes. Since the (d,q) voltage components are affected by the PWM ripple, their mean values are extracted for each electrical cycle and also for an integer number of mechanical revolutions.

The trajectories of the stator current vector in the (d,q) plane are useful to check the MTPA trajectory below the base speed.

(C) Estimation of the electromagnetic torque

The electromagnetic (or air-gap) torque can be computed by the Gen3i as

$$T_{est} = \frac{3}{2} \cdot p \cdot (\lambda_\alpha \cdot i_\beta - \lambda_\beta \cdot i_\alpha)\, dt \quad (12)$$

This electromagnetic torque is computed with flux components that have been evaluated by sampling the real motor PWM voltages and with a stator resistance that takes into account the measured average stator temperature. Therefore, this torque can be defined as the best torque estimate.

The Gen3i saves the electromagnetic torque as a mean value calculated over an integer number of mechanical revolutions.

Experimental Results

The above-described procedure has been applied for a PM-assisted synchronous reluctance motor having the following rated parameters: rated voltage (line-to-line) 310Vrms, rated current 17Arms, rated torque 22Nm, rated speed 3250 rpm, 4 poles. The definition of the rotating (d,q) reference frame uses the approach used for synchronous reluctance machines, as shown in Fig. 9.

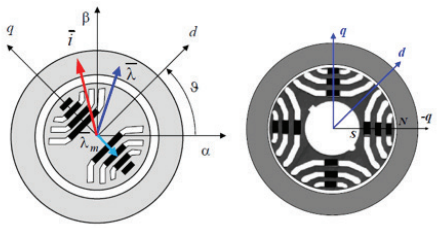


Figure 9: Definition of the (d,q) reference frame for the machine under test. Left : two-pole ideal machine, Right: real four pole machine

The d-axis is the minimum reluctance axis, while the q-axis is the maximum reluctance axis. The magnets flux linkage vector is aligned with the negative q-axis.

During the testing procedure, the speed is changed between 500 rpm and 7500 rpm with steps of 500 rpm (15 speed points), while the torque is controlled between zero and 38 Nm, with steps of 2 Nm (20 testing points). As a result, the mesh of operating points in the MUT torque-speed operating plane (Fig. 7) has 300 testing points.

The inverter that supplies the MUT is a standard IGBT inverter whose switching frequency has been set at 10 kHz. The inverter has been supplied with a constant DC voltage of 350Vdc that was provided by a constant DC voltage source of 340Vdc.

The obtained results are described in detail in the next subsections.

(A) Torque-speed

and power-speed maps

The measured torque-speed map is shown in Fig. 10, demonstrating the MUT torque capability. The maps of the input electrical power and the output mechanical power speed are illustrated in Fig. 11. At high speed operation, the input electrical power is almost constant, while the output mechanical power is slightly decreasing. This figure allows defining the constant power speed range given

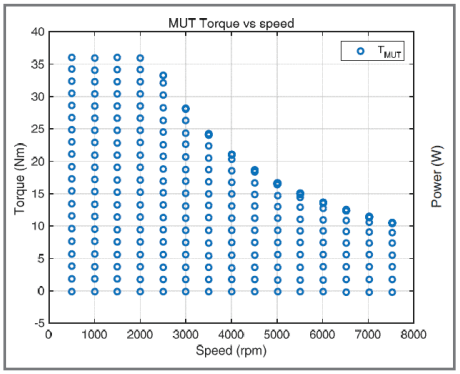


Figure 10: Measured torque speed map for the tested machine

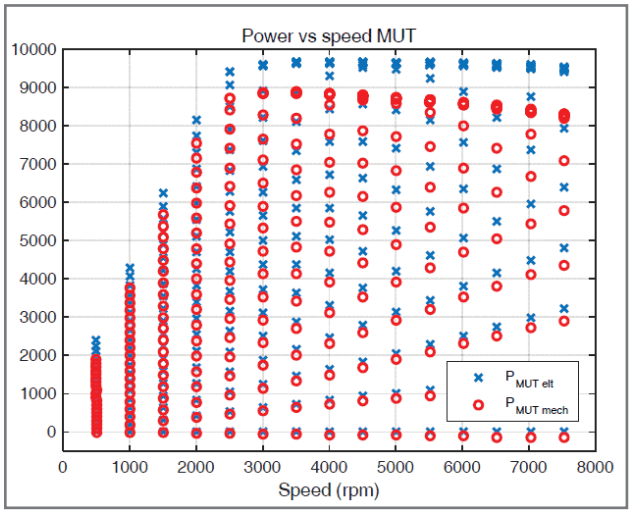


Figure 11: Measured output power- speed map and input power –speed map for the tested machine

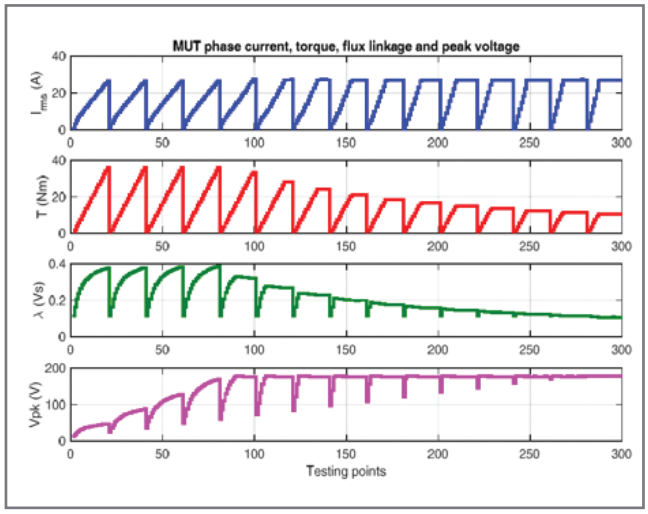


Figure 12: MUT phase rms current (A), measured torque (Nm), total flux linkage (Vs) and peak phase voltage (V). The first 20 points correspond to 500 rpm, the next 20 points correspond to 1000 rpm, while the last 20 points correspond to 7500 rpm

the target output power. From Fig. 11 one can see that the constant power speed range is about 1:3.

The rms phase current, the measured torque, the total flux linkage and the peak phase voltage are shown in Fig. 12 for the whole test. Fig. 12 is very useful since demonstrates that the total phase current is limited during the entire test. Moreover, it is very clear how the phase voltage is also limited at flux weakening and the flux is progressively reduced as the speed increases.

(B) Efficiency and loss maps

The efficiency map of the MUT is shown in Fig. 13, while the loss map is shown in Fig. 14. The efficiency map is extremely important to evaluate the motor efficiency for the entire torque-speed range. If necessary, the Gen3i can measure the inverter DC input power and consequently the inverter efficiency map and thus the drive efficiency map can be derived.

The copper loss map is provided in Fig. 15, while Fig. 16 contains the iron and mechanical losses map.

The time variations of the different MUT losess (copper loss and iron and mechanical loss), along to their sum (representing the total losses), are shown in Fig. 17. This result is very interesting since it shows that the copper losses are dominant up to 3500 rpm (testing point 140), while above this speed the iron and mechanical losses become important and they are equal with the copper losses at 7000 rpm. This result totally agrees with the individual loss maps shown in Fig. 15 and Fig. 16.

(C) Trajectories of (d,q) variables

The study of (d,q) variables allows a proper verification of the machine control. Using the measured rotor position, the GEN3i can easily obtain the (d,q) quantities (currents, voltages, flux linkages) to plot the trajectories of the corresponding vectors in the (d,q) frame during the test. As example, Fig. 18 shows the trajectory of the currents vector during the test, while Fig. 19 contains the trajectory of the flux linkage vector during the test.

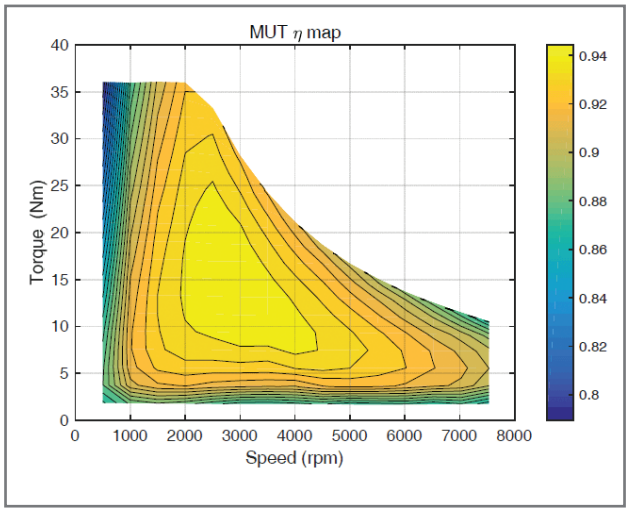


Figure 13: MUT efficiency map

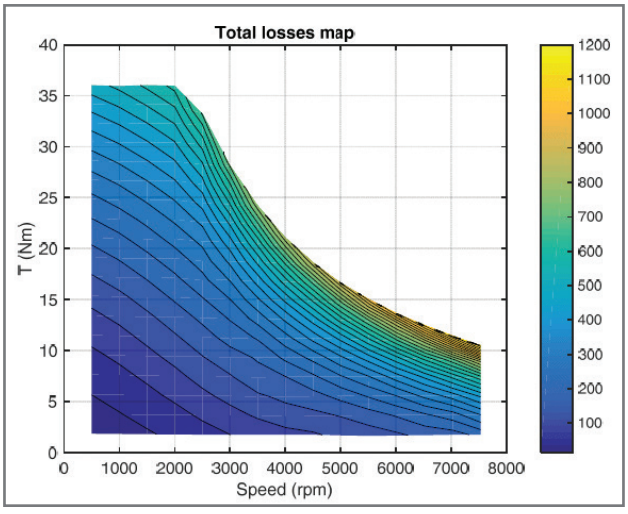


Figure 14: MUT loss map

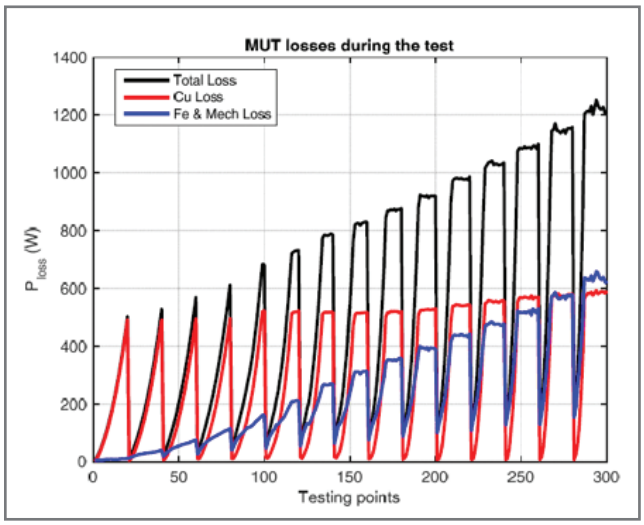


Figure 17: MUT losses (W) variations during the test (black – total losses, red – copper losses and blue – iron and mechanical losses).

The first 20 points correspond to 500 rpm, the next 20 points correspond to 1000 rpm, while the last 20 points correspond to 7500 rpm

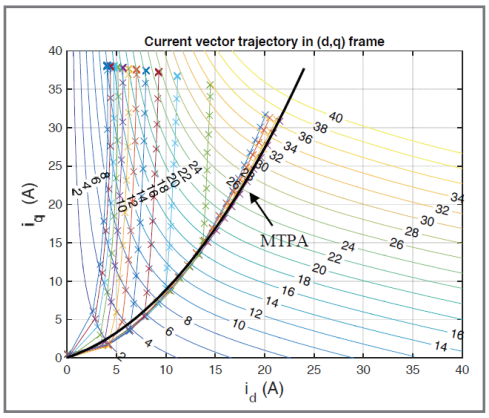


Figure 18: Trajectory of the current vector in (d,q) frame

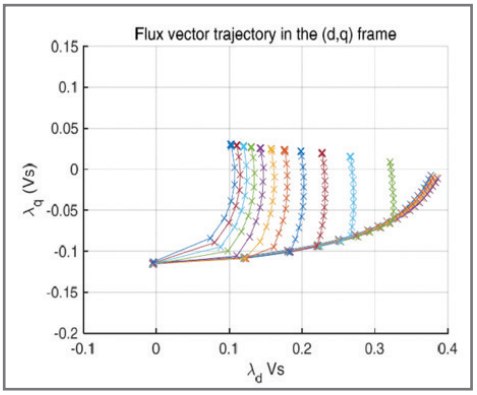


Figure 19: Trajectory of the flux linkage vector in the (d,q) plane

At low speed, both current vector and flux vector follow a trajectory (solid black line) that corresponds to the Maximum Torque per Ampere (MTPA) operation. At flux weakening, the current vector and the flux vector leave their optimal MTPA trajectories and approach the q-axis. The current vector keeps constant the maximum amplitude since the current is limited, while the stator flux vector amplitude is reduced, as should happen at flux-weakening operation.

The results from Fig. 18 allows checking if below the base speed the measured current vector really follows the MTPA trajectory to exploit in an optimal manner the MUT torque production.

Conclusions

The proper evaluation of an electrical motor requiresproper tools along with an automated procedure. This article focuses on the efficiency and loss mapping of AC motors. The torque-speedplaneis swept with the motor under test that must be rotated bya dedicated driving machine. For each operating point, the MUT control must generate a trigger signal to the HBM data recorder who measures all electrical and mechanical quantities. After the test, the HBM software performs all calculationson the acquired data and provides the efficiency, the losses, the motor flux linkages, the electromagnetic torque. Moreover, the (d,q) quantitiesthat are usually involved by the motor control can be also obtained. ●



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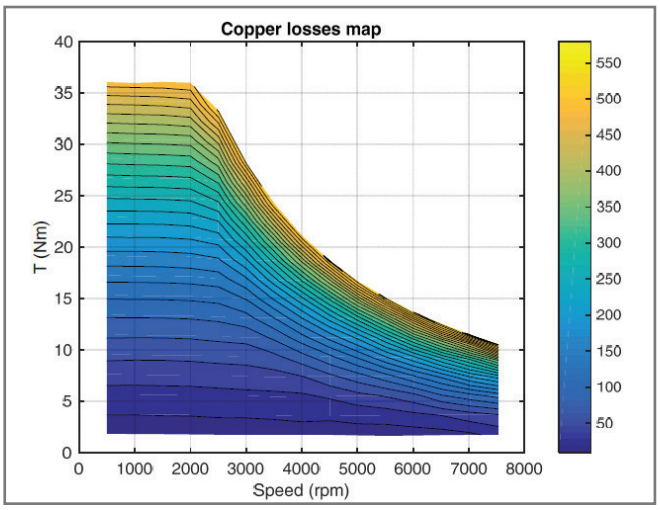


Figure 15: Copper losses map

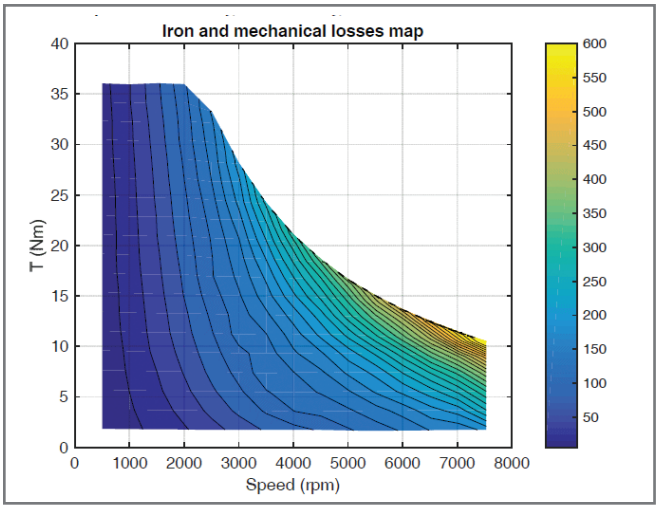
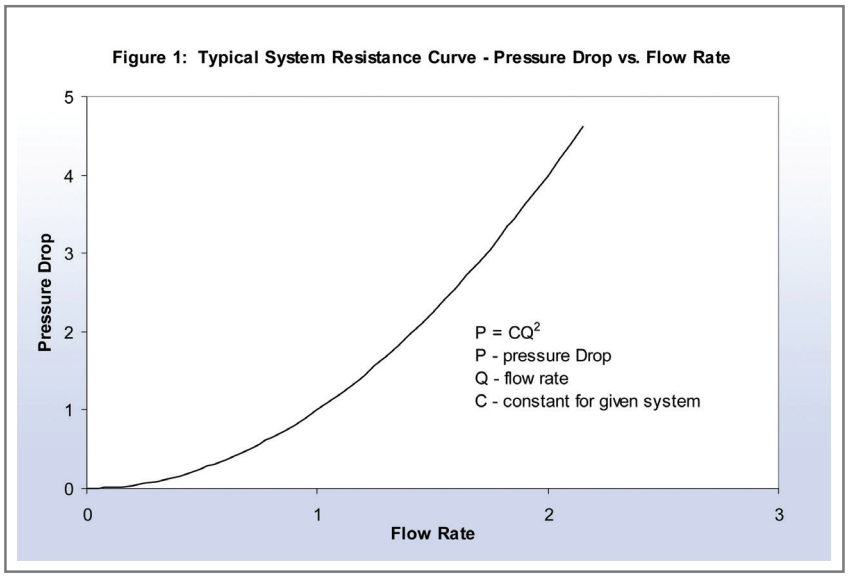
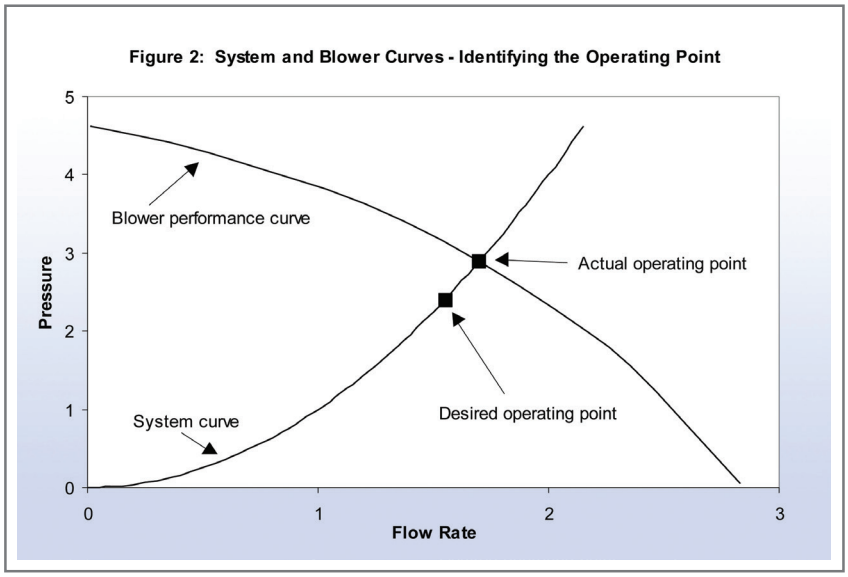


Figure 16: Iron and mechanical losses map





Selecting the Right Blower by Understanding Air Flow

BY EARL CLAUSSON

Selecting a blower for a particular application first requires knowledge or an estimate of the application's operating point: the flow rate required and the resistance to flow that the system, ductwork, filters, and other obstructions will impose. This resistance creates a loss of static pressure in the flow system, often referred to as backpressure or head loss, and each blower has a characteristic curve that describes the maximum amount of resistance that it can overcome to provide a given flow rate.

AMETEK Dynamic Fluid Solutions (DFS) performance curves represent each model's typical maximum performance (full speed) at a constant input voltage. The performance curve describes a blower's ability to deliver flow rate through resistance — from zero backpressure ("open flow") to completely blocked flow ("sealed"). Since all AMETEK DFS brushless DC (BLDC) blowers have adjustable speed control, any operating point that lies underneath a given performance curve can be reached, although there are several factors to consider beyond this.

With knowledge of the desired operating point, it is then a simple matter to identify blowers having performance curves that meet or exceed the desired operating point. Other factors should then be considered, which will be discussed below.

System Resistance Curve

A resistance to flow is typically characterized by a static pressure drop for a given flow rate, and often follows a 2nd order relationship (see Figure 1) (in some cases such as certain filters, the relationship is more linear). If the desired operating point is known, then its associated system curve can be estimated according to the relationship P=CQ2. Plugging the values for desired operating point into the P (pressure drop) and Q (flow rate) terms yields the constant C. The system curve can then be overlaid graphically onto a given blower performance curve. The intersection of the two curves is the actual operating point (see Figure 2). The static pressure rise provided by the blower matches the static pressure loss imposed by the system resistance. For quick checks, simply place the operating point on a given blower curve and "eyeball" the system curve through it.

There are likely to be several models that can achieve an application's performance requirement for flow rate and static pressure, but not all will necessarily operate with the same efficiency. AMETEK DFS blower performance curves include not only static pressure vs. flow rate information, but also current, rotational speed, and input power vs. flow rate. An application is normally best served by selecting the blower that delivers the desired performance with the best efficiency, i.e., the least amount of input power. For quick comparisons, a blower's peak efficiency lies near the middle of the flow range (i.e., about half the maximum flow rate) so it is recommended to look for blowers that have curves that intersect the system curve in the middle region rather than near the open flow or sealed points.

Other questions to consider when selecting a blower:

- What are the size constraints for fitting into my application?
- Would I prefer that the blower have an on-board brushless DC controller or would I prefer to provide an external controller?
- Do I need a blower with fast dynamic response?
- Is loudness a major factor?
- Does my application require modulating the speed during operation or simply a single speed adjustment made at the time of installation?
- What input voltage will I have available for powering the blower?
- Are there additional features that I require such as a tachometer output, dynamic braking, or speed control functions?
- Is it a problem for the working fluid to come into contact with electronics?
- What are the environmental factors associated with my application?

Gage Pressure vs. Absolute Pressure: When designing for air flow, it is common to come across pressure quantities that are described as "absolute" or "gage". Gage pressure is simply the difference above or below atmospheric (often called barometric) pressure. Absolute pressure is the sum of atmospheric and gage pressures: $P_{abs} = P_{gage} + P_{atm}$

Blower Performance vs. Speed Change

Since AMETEK DFS BLDC blowers are speed controllable, the speed can be reduced to a desired operating point or increased if a different operating point is needed in a dynamic system. Blowers conveniently have very predictable behavior when it comes to changes in speed. Table 1 summarizes these relationships.

Figure 3 with Example 1 demonstrates how to calculate the power requirement for an operating point that occurs at a reduced speed.

Example 1: An application calls for air performance of 8 cfm (ft3/min) at a static pressure of 6 inch H2O. The blower whose performance is shown in Figure 3 has been chosen. What will be the power consumption at 8 cfm, 6 in H2O?

Answer: At full speed, the blower will deliver about 8.8 cfm in this system, whose static pressure loss is about 7.2 in H2O at that flow rate (see Figure 3). Since this is delivering too much flow rate, the speed must be reduced to achieve the desired operating point.

At full speed, Figure 3 shows the

Table 1: Fan Laws Related to Changes in Blower Speed

$$Q_2 = Q_1\left(\frac{N_2}{N_1}\right)$$

$$\dot{m}_2 = \dot{m}_1\left(\frac{N_2}{N_1}\right)$$

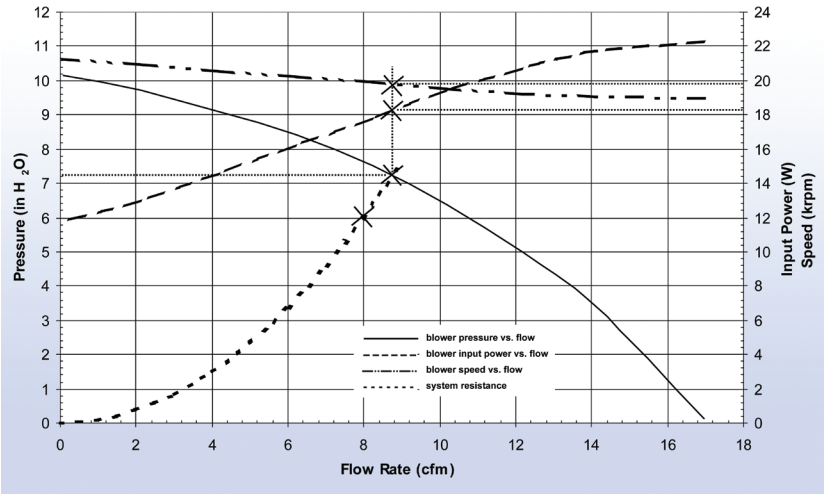
$$P_2 = P_1\left(\frac{N_2}{N_1}\right)^2$$

$$\mathcal{P}_2 = \mathcal{P}_1\left(\frac{N_2}{N_1}\right)^3$$

Where, $N \rightarrow$ fan rotational speed
$\dot{m} \rightarrow$ mass flow rate
$Q \rightarrow$ volume flow rate
$P \rightarrow$ static pressure (gage)
$\mathcal{P} \rightarrow$ blower power demand

All other variables constant.

Figure 3: Speed Change Calculation Example



blower speed to be about 19.8 krpm and the power consumption is 18.3 W. Using the fan laws shown in Table 1 yields:

$$8\ \text{cfm} = 8.8\ \text{cfm}\left(\frac{N_2}{19.8\ \text{krpm}}\right)$$

$$N_2 = 18.0\ \text{krpm}$$

So, the power consumption at the reduced speed is:

$$\mathcal{P}_2 = 18.3\ \text{W}\left(\frac{18.0\ \text{krpm}}{19.8\ \text{krpm}}\right)^3$$

$$\mathcal{P}_2 = 13.7\ \text{W}$$

The speed at the desired operating point could also have been found by using the ratio of pressures:

$$6\ \text{in}\ H_2O = 7.2\ \text{in}\ H_2O\left(\frac{N_2}{19.8\ \text{krpm}}\right)^2$$

Note: There is some minor error in this calculation because there will likely be some small change in motor efficiency at the different operating point. This can usually be neglected for estimating power requirements.

Fluid Density

The density of the working fluid has a significant influence on blower performance, as can be seen in the relationships listed in Table 2. Because fluid density is a variable that is independent of the blower, the density must be stated as part of any blower performance specification. In the previous example, the density was ignored for simplicity. But the performance curves for most AMETEK DFS blowers have the statement "corrected to density = .075 lb/ft3," or equivalent statement. So, in the previous example, it was assumed that the desired performance of (8 cfm, 6 in H2O) had also been corrected to .075 lb/ft3.

The density value of .075 lb/ft3 is a somewhat arbitrary selection, but it is close to typical air density at sea level. It is commonly referred to as "Standard Density" in the fan and blower industry. Any target operating point must be corrected to .075 lb/ft3 when evaluating blower performance curves. Examples hereafter demonstrate how to do this.

The vast majority of blower applications are designed to move air, but AMETEK DFS blowers can be used with any nonexplosive, non-corrosive gas mixture (Note: AMETEK DFS Nautilair® blowers are designed for combustion pre-mix applications). At the temperature and pressure ranges for most blower applications, the gas mixture can be considered an ideal gas, and it will behave according to the relationship: $\rho = \frac{PM}{R_u T}$

Where,

P = the absolute pressure

ρ = the density

Ru = the universal gas constant

T = the absolute temperature

M = the molar mass

For gas mixtures, the molar mass of the mixture can be determined from the weighted average of the component gases. Refer to texts on thermodynamics or contact AMETEK DFS engineering for help in calculating density for gas mixtures.

Air Density

Determining air density requires knowing the temperature, barometric pressure, and humidity of the working environment. Measuring temperature is relatively easy, but barometric pressure requires a barometer, and humidity requires either a wet bulb thermometer, a hygrometer, or a dew point detector. (Note: be careful if using barometric values obtained from weather services — they are corrected for altitude and may not match an actual on-site barometer measurement.)

Once these values are known, the easiest way to determine density is to use a psychrometric chart, which gives the properties of air for large ranges of temperature and humidity. (There are also online calculators available). Some notes on using a psychrometric chart:

1) Instead of density, the specific volume, which is the reciprocal of density, usually is plotted.

2) The specific volume is typically given in terms of volume per unit mass of dry air. But the working fluid is a mixture of air and water vapor (except at 0% humidity, of course). See the example hereafter for calculating the actual specific volume, i.e., volume per unit mass of the air-water vapor mixture.

3) Dry bulb temperature is simply the temperature measured using a regular thermometer.

4) For humidity, the wet bulb temperature can be used directly without having to convert to another type of humidity quantity. As an alternative, relative humidity or humidity ratio can be used.

5) Psychrometric charts are plotted at a single barometric pressure which is noted in the heading of the chart. A correction is needed to adjust density values to the actual barometric pressure.

Example 2: A laboratory makes the following measurements of the ambient air conditions:

Barometric pressure = 28.60 in Hg

Dry bulb temperature = 72° F

Table 2: Fan Laws Related to Changes in Fluid Density:

$$P_2 = P_1\left(\frac{\rho_2}{\rho_1}\right)$$

$$\mathcal{P}_2 = \mathcal{P}_1\left(\frac{\rho_2}{\rho_1}\right)$$

$$\dot{m}_2 = \dot{m}_1\left(\frac{\rho_2}{\rho_1}\right)$$

Where, $\rho \rightarrow$ fluid density
$P \rightarrow$ static pressure (gage)
$\mathcal{P} \rightarrow$ power demand
$\dot{m} \rightarrow$ mass flow rate

Note: volume flow rate, Q, is independent of density for gases.

Wet bulb temperature = 65° F

What is the ambient density?

Answer: Using a psychrometric chart plotted at 29.921 in Hg, the intersections of the curves corresponding to the dry bulb and wet bulb values above yields a specific volume of 13.64 ft3/lbdry air and a humidity ratio of .0116 lbwatervapor per lbair. Correct the specific volume per lb air-water vapor mixture:

$$\frac{m_{wv}}{m_{air}} = .0116$$

$$m_{mixture} = m_{wv} + m_{air}$$
$$= .0116m_{air} + m_{air}$$
$$= 1.0116m_{air}$$

$$\frac{m_{air}}{m_{mix}} = .989$$

$$.989(13.64\ ft^3/lb_{air}) = 13.49\ ft^3/lb_{mix}$$

Finally, correcting this value for the actual barometric pressure yields:

$$13.49\ ft^3/lb_{mix}\left(\frac{29.921\ in\ Hg}{28.60\ in\ Hg}\right)$$

$$= 14.12\ ft^3/lb_{mix}$$

$$= .0708\ lb_{mix}/ft^3$$

The density of air varies substantially with weather and altitude. The Standard Atmosphere Table (not included herein, but widely available in reference texts and internet sites) gives a good estimate for typical outdoor ambient conditions as a function of altitude. The following example demonstrates how to account for the lower density at high altitude:

Example 3: An application calls for a blower to deliver 50 cfm of air at 30 inch H2O at an altitude of 7000 ft above sea level where the average air density is 0.062 lb/ft3, according to the Standard Atmosphere Table. For the purpose of selecting a blower, what operating point should be used?

Answer: Refer to Table 2. Since volume flow rate does not change with density, the flow rate remains at 50 cfm. The pressure does change in proportion to density:

$$P_2 = 30\ inch\ H_2O\left(\frac{.075\ lb/ft^3}{.062\ lb/ft^3}\right)$$

$$P_2 = 36.3\ inch\ H_2O$$

So, the operating point corrected to standard density is 50 cfm, 36.3 inch H2O.

Example 3 continued: A blower is selected that can deliver the above performance with a power demand of 600 W at standard density, as shown on the performance curves. What will be the power demand at the intended location at 7000 ft altitude?

Answer: Refer to Table 2 for correcting power demand for a change in density.

$$\mathcal{P}_2 = 600\ W\left(\frac{.062\ lb/ft^3}{.075\ lb/ft^3}\right)$$

$$\mathcal{P}_2 = 496\ W$$

Example 3 continued — Redefining the problem in terms of mass flow rate: The application requires a mass flow rate of 3.1 lb/min of air regardless of altitude.

A) How much must the speed be reduced if the application is moved from a location at 7000 ft (.062 lb/ft3) to sea level (.075 lb/ft3)?

B) How much will the power demand change?

Answers:

A) Table 2 shows that the change in mass flow rate is a simple ratio of the densities. If the blower speed is maintained between the two locations, the mass flow rate delivered at sea level will be:

$$\dot{m}_2 = 3.10\ lb/min\left(\frac{.075\ lb/ft^3}{.062\ lb/ft^3}\right)$$

$$\dot{m}_2 = 3.75\ lb/min$$

Mass flow rate is directly proportional to a change in speed (Table 1), so to maintain 3.1 lb/ft3, the speed must be reduced by:

$$3.10\ lb/min = 3.75\ lb/min\left(\frac{N_2}{N_1}\right)$$

$$\left(\frac{N_2}{N_1}\right) = .827 = 17.3\%\ reduction$$

B) Tables 1 and 2 show that the power demand is directly proportional to both density and speed, although a speed change has a much larger influence. Combining both relationships yields:

$$\mathcal{P}_2 = \mathcal{P}_1\left(\frac{\rho_2}{\rho_1}\right)\left(\frac{N_2}{N_1}\right)^3$$

$$\mathcal{P}_2 = \mathcal{P}_1\left(\frac{.075\ lb/ft^3}{.062\ lb/ft^3}\right)(.827)^3$$

$$\mathcal{P}_2 = .684\ \mathcal{P}_1 = 31.6\%\ reduction$$

The above is intended to be an overview of initial steps in selecting the best AMETEK DFS blower for your application, and AMETEK DFS welcomes any questions you might have.



Earl Clausson *is the Principal Engineer at AMETEK Dynamic Fluid Solutions. 27+ years in the fluid motion industry - primarily centrifugal blowers and pumps. Design responsibilities have covered not only the fluid motion aspects, but also electric motor construction (BLDC) and incorporation into overall package. New product development, applications engineering, customer and manufacturing support. I have designed and built several test stands for testing blowers and pumps in the laboratory and factory. Licensed Professional Engineer in the state of Ohio since 2008.*



EMC Compliance Considerations and Requirements For The UK and The EU

BY JACK BLACK AND MARK ROZEMA

When the UK voted to leave the European Union, many changes took place with respect to regulatory requirements for goods placed on the market in the UK. This article will focus on the EMC related requirements, and how those requirements effect manufactures placing products into the UK market, and the incorporation of a formalized regulatory compliance mark, the UKCA Mark, which is separate from the common CE Mark for applicable goods placed on the market in the EU.

The UK will, as of January 1, 2023, no longer accept goods marked with the CE Mark, nor use standards that are not specifically recognized with the UK regulatory agencies. The UKCA marking will not be recognized on the EU or Northern Ireland markets. Products currently requiring a CE marking for sale in the EU will continue to need a CE mark (and meet the other EU rules). Goods marketed in both the UK and the EU must bear both the UKCA and CE marks.

Manufacturers are encouraged to prepare to use the UKCA marking for the UK market as soon as possible, as it is considered voluntary until January 1, 2023, when it becomes mandatory. Before that date manufacturers do not need to change the conformity marking on product if it is CE marked and if either of the following apply:

- you self-declare the conformity of your goods against the regulations
- you voluntarily use a testing or notified body to test against European or international standards

You may need to take additional action if your goods need third-party conformity assessment. Manufacturers will need to check whether their EU approved body is taking steps that help you continue to export to the UK, as formal registration as an UK Conformity Assessment Bod will apply.

UK compliance and the UKCA Mark is formally separate from the EU and CE Mark requirements and includes commerce in the following countries as part of the United Kingdom:

England, Scotland, Wales

TABLE 1: EU AND UK Regulatory Legislation Comparisons

EU Legislation	UK Legislation
Electromagnetic Compatibility - Directive 2014/30/EU	Electromagnetic Compatibility Regulations 2016
Low Voltage Directive 2014/35	Electrical Equipment (Safety) Regulations 2016
Radio equipment - Directive 2014/53/EU	Radio Equipment Regulations 2017
Restriction of the Use of certain Hazardous Substances in Electrical and Electronic Equipment (RoHS) - Directive 2002/95/EC	The Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations 2012

EMC Regulatory Requirements and Agencies

As the EU Council of Ministers publishes a series of directives or regulations, which are considered law for commerce in the EU and the EEA, the UK has similar regulatory legislation which is compared in the table 1.

Manufacturers and companies that place products into the UK marketplace will need to meet similar regulatory practices.

Standards and Applied Use

Appliances and similar devices, such as restaurant equipment, will need to meet the separate regulatory legislation requirements in the UK, as well as in the EU. This is usually done by testing to an acknowledged standard listed in the regulatory registration. For the EU, this listing is provided in the applicable directive as confirmed by publication in the Official Journal of the European Union. For the UK, these listings are provided by the UK Department for Business, Energy & Industrial Strategy.

Compliance standards are established by international organizations which use representative committees from global countries, regulatory agencies, and industry representatives. Examples of these internal organizations are the International Electrotechnical Committee (IEC), the European Committee for Electrotechnical Standardization (CENELEC), or European Telecommunications Standards Institute (ETSI). These standards are published and offered to regulatory agencies in each country, where each country's legislative organization publishes and enters into their own laws the specific standards. Each EU member state publishes their own versions of these internationally recognized standards, and likewise the UK publishes their own standard as well.

Recent UK published standards have been decoupled for use in the EU. What this means is that referenced BSI standards can't be used for compliance for the EU. Only recognized member state harmonized standards can be used for CE compliance.

For the UK the list of standards published as of the date of this article can be found at www.gov.UK and include mostly EN based standards. What this means is that the standards used for EU compliance can also be used for compliance in the UK, provided they are applicable and are considered current.

EMC Standards

BS EN 55014 standards have been published by the British Standards Institute, with an effective date of 2021-09-26, and a withdrawal date for the previous standards EN 55014-1 and -2:2017 of 2023-10-05. These new standards are comparable to the EN IEC 55014 standards, with the same effective and withdrawal dates, and products tested using these standards with compliant test results would be able to declare the presumption of conformity for the EU and the UK.

PART 1: EMISSIONS
Electromagnetic Compatibility Requirements for household appliances, electric tools and similar apparatus

EN 55014-1:2017	BS EN IEC and EN IEC 55014-1:2021
No categories as in the immunity, however there are modes of operation specified for certain types of equipment	No categories as in the immunity, however there are modes of operation specified for certain types of equipment
Radiated testing is performed only up to 1GHz	Radiated testing is performed up to 6GHz, depending on highest clock frequency: • Fx ≤ 108MHz, test up to 1GHz • 108MHz < Fx ≤ 500MHz, test up to 2 GHz • 500MHz < Fx ≤ 1 GHz, test up to 5GHz • Fx > 1GHz, test up to 5 x Fx, up to a maximum of 6 GHz.



A comparison of standards to their previous version is referenced in Part 1 and Part 2 charts:.

It is important to note that this new BSI published standard is not considered acceptable for CE mark compliance, as it has been decoupled from the EU EMC directive. Only EN standards can be used for CE mark compliance.

PART 2: IMMUNITY

Electromagnetic Compatibility Requirements for household appliances, electric tools and similar apparatus

EN 55014-2:2017	BS EN IEC and EN IEC 55014-2:2021
4 Categories • Category I: apparatus containing no electronic control circuit • Category II: AC mains operated equipment with internal clock <15MHz • Category III: Battery operated equipment not included in category I with internal clock <15MHz • Category IV: all other equipment not covered by other categories	5 Categories • Category I: apparatus containing no electronic control circuit • Category II: AC mains operated equipment with internal clock <15MHz • Category III: Battery operated equipment not included in category I • Category IV: AC mains operated equipment with internal clock >15MHz but <200MHz • Category V: AC Mains operated equipment with highest clock frequency >200MHz
IEC 61000-4-2: ESD	**IEC 61000-4-2: ESD**
• +/-4kV Contact • +/-8kV Air • No lower levels need to be tested • Categories: II, III, IV	• +/-4kV Contact • +/-8kV Air • No lower levels need to be tested • Categories: II, III, IV, V
IEC 61000-4-3: Radiated Immunity	**IEC 61000-4-3: Radiated Immunity**
• 80-1000MHz: 3V/m (1kHz, AM) • Categories: III, IV	• 80MHz-6GHz*: 3V/m (1kHz, AM) • +/-8kV Air • Categories: III (up to 1GHz), IV (up to 1GHz), V (up to 6GHz)*
IEC 61000-4-5: Surge	**IEC 61000-4-5: Surge**
• AC Power: +/-2kV L-GND, +/-1kV L-L • Positive discharge at 90 degrees, Negative at 270 degree phase angle • No lower levels • Categories: II, IV	• AC Power: +/-2kV L-GND, +/-1kV L-L • Signal: +/-1kV L-GND (unshielded), +/-0.5kV L-GND (Shielded) • Positive discharge at 90 degrees, Negative at 270 degree phase angle • No lower levels • Categories: II, III, IV, V



IoT/Wireless Standards

Products placed on the market with wireless capabilities, i.e. Bluetooth, WI FI or other wireless features fall under the guidelines of the EU Radio Equipment Directive (RED), and the UK Radio Equipment Regulations.

Current processes involve the use of ETSI standards, those that are published by the European Telecommunications Standards Institute. These standards provide the regulatory guidance for wireless products and include wireless modules and devices that incorporate them. The UK has participated in the development of these standards and is expected to continue to follow those guidelines used in the past. Manufacturers will continue to be responsible for the wireless features, including transmitter regulations.

Current legislation in the UK is found in the UK Radio Equipment Regulations 2017. As of the writing of this article, there has not been an update for UK radio equipment regulations and standards. Products will still need to meet the requirements in a separate manner after Jan 1, 2023, with both CE and UKCA marks on the products, and separate manufacturers Declaration of Conformity, citing legislatively approved standards in each instance, or the EU and the UK as separate requirements. Anticipated changes for standards for UK compliance have also not been updated at this time. It is important to monitor the the www.gov.UK web site to determine compliance paths when new standards are identified.

EMC Consideration for Product Safety Standards

Products that incorporate an electronic interface that provides a stand-by mode, an electronically controlled safety circuit, or other safety related control features, would need to consider the requirements in

EN or BS EN 60335-1, under section 19.11. These features might include, but are not limited to, overtemperature detection, operational lockouts, and/or other features critical to the safety of the device. These tests are specific to immunity or susceptibility requirements, as are part of the compliance process for product safety under the EU Low Voltage Directive (LVD), or Radio Equipment Directives (RED) and the UK equivalent Electrical Equipment (Safety Regulations) and Radio Equipment Regulations.

These tests follow the test procedures referenced in BS and EN IEC 55014-2; however, there will be different, more stringent levels in some cases, and the monitored conditions of acceptability will be specific to unsafe conditions in the stand-by and electronically controlled safety operating modes.

Also noted in this standard is the removal of any supplemental or auxiliary surge protecting devices installed or supplied with the equipment and considered outside surge protective circuitry in the controlling features of the equipment under test.

Restrictions on Hazardous Substances

As the EU has the RoHS Directive requirements for CE mark, the UK will have similar requirements for the UKCA mark. The Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations 2012 is the most current legislation in the UK and follows the EU guidelines and are expected to be maintained. This may also include new updates and will require manufacturers to monitor any changes that may take place.

Current Products on Market

Any product placed into the UK market prior to January 1, 2023, can bear the EU CE mark, and use current EU recognized standards, without the UKCA mark. Any product placed on the market after Jan 1, 2023, must bear both the CE Mark and the UKCA mark.

When deciding to add the UKCA mark to current products, manufactures must determine the applicable legislation and associated regulatory standards that would be used on their product today and compare them to those that were in place when the product was originally tested.

For appliances and similar devices, many of the tests are identical, however, some changes have been made when updating the standards. A gap analysis should be performed to determine if additional testing is required, or if existing testing is within the application legislative standards. The test results from previous compliance paths should also be reviewed to determine if they are within the acceptable guidelines of the latest standards.

In the event the product has not changed, and the gap analysis shows continued compliance, manufactures can claim compliance providing they have accurately referenced the appropriate standards and test levels. Manufacturers should also consult with their testing partners to determine how best to document this compliance, and how to update their technical file.

UKCA Declaration of Conformity

Manufacturers must provide a UK Declaration of Conformity when applying the UKCA mark. This will have the same open format as the EU Declaration of Conformity, but must be a separate document, citing similar information regarding the standards and legislation referenced. Products placed on the market in the EU and the UK must have two separate documents.

Authorized Recognized Representative

For UKCA compliance, it is recommended in all cases, and required in some, that a legal authorized representative be referenced on the UKCA declaration of conformity. It must be noted that only a UK located representative can be referenced. If a manufacturer uses a notified body for their compliance, the notified body must be registered in the UK.

Summary

The CE mark can be used until Jan 1, 2023. The UKCA mark is encouraged but not mandatory.

The UKCA mark is mandatory starting Jan 1, 2023.

Products can be marked with both UKCA Mark and CE.

A Separate Declaration of Conformity will be needed for UKCA compliance even during the transition period when using the UKCA mark.

The UKCA mark may have different standards and different requirements than EU compliance with the CE Mark provisions.

Existing products tested to a previous standard should be reviewed to determine if current testing results can be used for UKCA compliance, and if not, it will need to be determined as to what testing should be done to show compliance.

Use of current active standards is required, noting date of withdrawal.

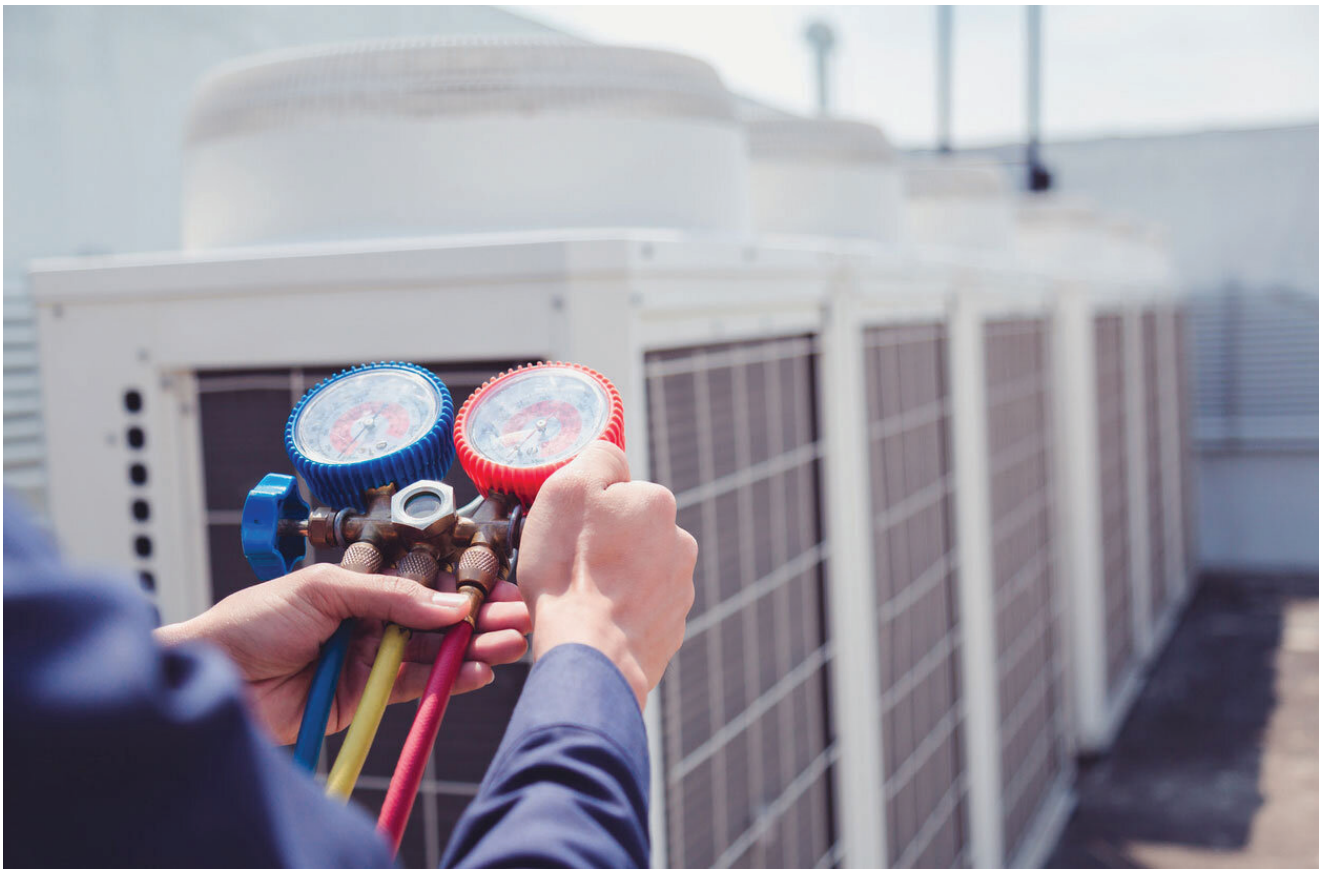
Monitor www.gov.UK web site for updates. More information can be found at www.dlsemc.com. ●



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A Discussion of IAQ vs Sustainability

BY RUSSELL McNEICE

In today's Covid aware environment, there are many discussions and solutions being offered to address Indoor Air Quality (IAQ). After reading many articles on the subject published by engineering societies, contractors and HVAC equipment manufacturers, I believe it is critical to look at the bigger picture of what is physically possible versus what is economically feasible.

To address IAQ in a logical and sensible manner the first consideration must be equipment maintenance. Many at the academic level seem to have a false belief that equipment is being maintained at or better than equipment manufacturer recommendations. Nothing could be farther from the truth. Most systems receive what is quaintly termed as demand maintenance. This means when it breaks fix the least amount possible to get it back operating again, this is not maintenance, it is component repair.

Many systems for public spaces have been turned off, shuttered or operating at very minimal requirements for 2 years or longer, with no maintenance or repair. The first step must be a thorough cleaning and maintenance of the systems. The same care and attention should be given to HVAC equipment as a building owner or operator would give to any touch surface that customers or employees would touch. Cleaning and sanitizing the HVAC surfaces is paramount to any IAQ program.

The general industry wisdom currently to address IAQ is to improve air filtration at the unit. Many existing systems are designed and currently use MERV 4 filters. Many are recommending up grading to MERV 13 or higher filters. While this may seem like an easy solution, it has many issues to overcome. First, most filter systems are designed to hold a filter that is 2 inches thick, the higher MERV filters are typically much thicker and will require modifications to the filter racks. Next a MERV 13 filter will have a much higher resistance to airflow or higher static pressure drop which will result in reduced airflow, higher fan horsepower requirements and increased energy consumption. Many systems will not be able to handle this additional load and it is likely that fan motors will have to be

changed out and possibly even fan blades or blower wheels. None of this conversion can be done accurately or with any certainty without having an initial test and balance report done and a post test and balance report to show that the desired airflow has been achieved. This adds up to very large expenses, that most equipment owners do not have a budget for and the return on investment could be decades, while paying 3 to 3.5 times as much for filters that will have to be changed more frequently due to faster dirt loading on higher efficiency filters.

At the same time everyone is being constantly barraged with an emphasis to be green, reduce carbon emissions and to achieve Sustainability. The filter solutions that are being proposed are in direct conflict with the goals of Sustainability and financially would rarely make sense for the equipment owner.

To achieve IAQ and Sustainability in a feasible cost-effective manner, it is critical to take the approach of keeping clean healthy surfaces within the HVAC systems, primarily the evaporator coils and drain pans where most biological growth happens that can affect IAQ. There are many add on devices in the marketplace such as UV lamps, ionic systems, ozone generators and many more. Each one of these requires physical modifications to the systems and additional ongoing maintenance to keep them operational. They also require energy to power them.

I would propose a proper coil and system cleaning first, followed by a long-term antimicrobial coating for evaporator coils and drain pans, which would provide long term surface protection.

The evaporator coil and drain pan environment is typically a cool, dark and wet space, which is ideal for fungi, bacteria and viruses to colonize and grow. We must address these spaces to have any effective long-term or meaningful effect on IAQ.

With over 45 years in the HVAC industry, working with mini split systems to very large central plant environments, it is clear that good maintenance, coupled with an antimicrobial coating such as CoilSafe Plus™, this will protect the coil and drain pan surfaces against damaging corrosion and microbial contamination. The cleaner the surfaces the greater the chance of improving IAQ. This approach also does not require additional maintenance or component replacements as it ages. It also does not require any additional energy and will save energy in the long term.

In speaking with many professionals from the HVAC manufacturing and contractor side of the industry, there has been a lot of push back to any coating product that could extend the life cycle of equipment. This is understandable, since their business is to manufacture, sell or install new systems.

What many do not consider is that 80% or more of the entire HVAC marketplace is equipment that is already installed, meaning that they are spending most of their time protecting and chasing the new or replacement unit market, which is only 20% of the marketplace.

Unit replacement or installation typically only happens when the building has a change of cooling load or equipment is aged and not worth repairing. This cycle can be 3 to 20 years between change outs and is not a stable income for the manufacturer or contractor.

I am aware that everyone from the building owner, to the contractor, to the manufacturer must see a financial advantage or gain from any money being spent on HVAC systems, so I propose this scenario.

The building owner contracts with the contractors to do proper routine maintenance and coat their coils with antimicrobial coating. This saves the building owner expense dollars in energy cost due to proper running equipment, reduce cost for failures due to lack of maintenance and extended equipment life reducing capital cost expense and contributing to sustainability and reducing greenhouse gasses.

The contractor will experience more reliable cash flow through maintenance agreements and will experience a more positive relationship with their customers, creating customer loyalty, instead of an owner jumping from contractor to contractor seeking cheaper solutions or solutions that the contractor has not provided.

The HVAC equipment manufacturers will have equipment that is more reliable and efficient, creating brand loyalty and reducing warranty claim expenses.

In this scenario, everyone benefits financially, IAQ is improved, and sustainability is achieved while using green, sustainable, and sensible solutions. ●



Russell McNeice *has over 45 years in the HVAC industry serving in multiple roles, technician providing service and installations, facilities manager, regional tech support manager providing remediation and forensic engineering of critical cooling systems failures and national energy manager for a fortune 500 telecom.*

Currently serving as the Chief Technical Officer of Coat Zone Inc., providing technical support and product development to address corrosion, microbiological contamination of HVAC surfaces and reducing solar heat gain on HVAC equipment and building envelopes.

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