Proposed Research
TC 1.9 Electrical Systems
Adapting HVAC Systems to Operate Under Duress
DRAFT

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ASHRAE Technical Committee 1.9 Electrical Systems
1 August 2002

A program for co-funded ASHRAE research relating to response to extreme events and anticipated harsh power system environments.

BACKGROUND

Operating Environment

Of late, HVAC systems, and buildings in general, are experiencing a very different quality, adequacy and reliability of electrical service. The primary contributors to this are:

- Increased use of distributed energy resources (power generation, storage, responsive load) for economic, reliability, security, and power quality reasons.
- High loading of the transmission and distribution system, caused by electric sector deregulation, third party access and competition, greater than normal long distance power transfers, transmission bottlenecks, and spot shortages of electric capacity.

Distributed energy resources (DER) are not as good at load following or maintaining power quality as a secure, well-regulated central power system. Also, when a facility is served by local generation (for economic reasons or in back-up mode), non-critical loads may be curtailed, which could result in imbalance among the 3 phases of the facility's power distribution system. When electric power to a facility is supplied in whole or part by local electric generation (or storage) or by a stressed power grid, the following are likely consequences:

- Voltage excursions
- Frequency excursions
- Phase imbalance
- Momentary interruptions
- Transients (e.g., surges)

This is hard on building HVAC and associated systems (motors, compressors, control systems, etc.) and, to protect themselves, such systems will trip out when faced with poor quality power. However, if the facility must operate under such conditions for extended periods of time, for economic or security reasons, one cannot afford to have the HVAC unavailable. One solution is to install "hardened" HVAC systems that can withstand such disturbances.

Is There A Problem?

Precise control of temperature and humidity is essential for the National Archives II building in College Park, MD. For this reason, the Archives installed state-of-the-art hardened, microprocessor-controlled chillers in 1994. These units were designed to ride through most disturbances, but the facility experienced numerous chiller shutdowns, usually associated with voltage sags on the utility system that coincided with bad weather.

These chillers had been designed to withstand such sags. The Archives and the electric utility investigated the problem, using the Power Electronics Applications Center (PEAC) of the Electric Power Research Institute. PEAC monitored the site's power quality and the response of the chillers. PEAC also installed a similar chiller in a controllable test site.

They found that the chillers tripped off soon after (not during) voltage sags. The problem originated in the settings of the control relays and their interaction with the chillers' microprocessor control. A number of steps were prescribed that successfully "desensitized" the chillers. Subsequent work by PEAC with the chillers' manufacturer and 4 other major chiller manufacturers found similar problems with all 5 companies' units.

DER prime movers do not have the load following capabilities of utility power systems; local DER and micro-grids will not have the large inertia of an interconnected power system. This means that a facility relying in whole or part on local self-generation can expect frequent voltage sags and unbalanced voltages as loads in the facility turn on and off. The "excursions" from ideal voltage and current levels can be expected to be more numerous and more severe than the consequences of the relatively well-defined conditions faced by the National Archives II facility.

Interruptions of HVAC systems and/or mistakes in their controllers' commands can have severe consequences for a facility – both indoor environment/air quality and process cooling of electronic equipment (communications and data centers, for example). As more "critical" facilities are installing DER to improve the facility's power quality and reliability, and as grid instabilities and electric price spikes proliferate, there is more economic incentive to utilize the DER on a routine basis instead of just in an emergency back-up mode. As a result, building HVAC systems can expect to operate in a significantly harsher environment.

We expect that continued reliance on distributed energy resources and/or central power systems that are to some degree unstable will result in unacceptable behavior of essential building systems.

SCOPE OF THE RESEARCH INITIATIVE

The proposed initiative has 4 major aspects:

- Characterize the electric power environment under extraordinary conditions
- Develop Standards/Specifications for hardened HVAC and auxiliary systems
- Develop procedures to test whether a system complies with the Standard
- Develop Emergency Building Performance Standards

We are concerned with *long-term* or *chronic* degradation of power quality or voltage and frequency support to buildings. Current standards for uninterruptible power supplies, back-up generators, etc. cover short-term outages. The proposed Standard will address:

- Maintaining a comfortable indoor environment for buildings that for economic reasons often rely on self-generation for all or part of their electrical needs. An example is an office building using a micro-turbine, desiccant system utilizing waste heat from the turbine, and ice storage to provide power and space cooling for 6 hours each day during peak load periods.
- Maintaining an acceptable and healthy environment in facilities essential for public health and safety during long periods of self-generation and/or poor grid stability due to extraordinary events. An example would be a police station, hospital or airport operating on emergency power for an extended period because of a natural disaster.
- Providing adequate space conditioning and power for key processes. An example would be supplying electricity and cooling the electronic systems of a telephone switching center, financial data processing facility, or Internet provider.
- Prioritizing loads in a facility when available power capacity is less than the demand. This is similar to current practices of providing back-up to critical circuits during an outage, but with the flexibility of being able to modify the demand, increasing some loads while decreasing or dropping others. Examples are continuing to run ventilation while shutting down chillers during a power outage, increasing ventilation for smoke removal during a fire in a high-rise building, or switching on spot cooling units during an outage in a data processing center.

While DER has important applications in rural areas, this research will focus on urban areas and large commercial facilities.

There is valid interest in being able to handle extreme events – natural disasters or terrorist attacks. However, it is important to recognize that the power system of the future will be *characterized by everyday operation under stressful conditions* as DER generation or responsive loads are dispatched routinely in response to real-time electricity price signals.

CHARACTERIZE THE ELECTRIC POWER ENVIRONMENT

This first step consists of defining "scenarios" and then characterizing the power quality problems a facility can expect to experience under each scenario. The power environment will be characterized by:

- Frequency stability
- Voltage stability (sags, etc.)
- Voltage phase balance
- Current transients
- Harmonics
- Interruptions

The scenarios will be characterized by operating conditions and power supply. The operating conditions will include:

- Normal operations

- Stressed operations, including heavily loaded power systems (i.e., near peak capacity), inclement weather (thunderstorms, ice storms, heat waves, etc.)
- Emergency conditions, including large power outages (with power system islanding), natural disasters or deliberate sabotage. The emergency conditions may range from short duration (e.g., 3 to 6 hours) to several days or a week.

The facilities' power supply will be classified according to:
- Grid-connected operations (i.e., what is the power quality supplied by the utility system)
- Parallel operations of various types of facility-sited DER (generation, storage, UPS, responsive loads, etc.) with the utility grid – i.e., the utility and the DER supply power to the facility simultaneously
- Grid-independent operations – the facility is separated from the utility and generating all its own power. This may be due to emergency conditions, economics, or inability of the DER to operate in parallel with the grid due to constraints imposed by IEEE Standard 1547.

Data on the power environment will be obtained by:
- Monitoring power quality and reliability on selected sites and in selected facilities
- Testing HVAC and DER systems in laboratory settings, in response to controlled conditions, including simulated power disturbances.
- Modeling power system quality response to DER and HVAC operations. (i.e., computer simulations)

Expected output:

Characterization of the expected power environment HVAC systems will see

Previous work:

Characterization of utility distribution system power quality and facility power quality (especially that experienced by HVAC systems) – by EPRI, PEAC, and numerous utilities

Operating experience of DER prime movers (e.g., micro-turbines) and packaged DER-building HVAC system units – Oak Ridge National Laboratory

Possible co-funding:

DOE Office of Power Technologies, EPRI and its utility members (suggested contractor – PEAC, under the direction of ORNL and associated national laboratories)

STANDARD/GUIDELINE FOR HARDENED HVAC AND AUXILIARY SYSTEMS

HVAC systems can be built to withstand almost any conditions, at a cost. This research activity will compare the power quality environments predicted in the previous activity with the ride-through capabilities of HVAC systems. Working with HVAC vendors and installation contractors, the research will estimate what is needed – in design of new units and retrofit of existing ones – for HVAC systems to operate under the forecasted power system conditions, and the costs of those measures.

At that point, an ASHRAE Standards Project Committee will develop consensus guidelines about what power quality conditions HVAC equipment and auxiliary systems should be able to withstand. This will vary by type of facility; an airport control center's computer room will need to be "hardened" more than a retail store.

To meet needs of possible co-funders, this guideline may cover more than HVAC systems. It may be expanded to prescribe

- The capacity (kW) and energy (kWh) an uninterruptible power supply or back-up generator must be able to supply (i.e., what loads and for how long)
- The performance under stress required of other building systems – such as elevators, lighting, power for computers, domestic water, smoke removal, etc.

Expected output:

Guideline for what types and degrees of power system disturbances HVAC systems should be able to withstand. The guideline may specify different degrees of "hardening" and state where each degree of robustness is appropriate. For example, a hospital's HVAC system or a communication center's cooling system may be expected to be more rugged, for a longer period of time, than a restaurant's.

Previous work:

EPRI-PEAC National Archives II and EPRI Target 34 Chiller studies.

Possible co-funding:

DOE, HVAC manufacturers

TEST PROCEDURES

This activity will develop the procedures and criteria to determine whether facilities and HVAC systems meet the Guideline's requirements.

Expected output:

Test procedure to verify that an HVAC system meets the Guideline.

Previous work:

Test procedures have been developed by ASHRAE, DOE, EPRI, NEMA, etc.

Possible co-funding:

DOE, HVAC manufacturers, EPRI

EMERGENCY BUILDING PERFORMANCE STANDARDS

This final step goes well beyond ASHRAE, as it addresses the ability of critical infrastructure to function under extreme conditions. However, the approach taken can parallel that now used to certify energy efficient facilities that provide comfortable and healthy indoor environments – such as the EnergyStar program.

A “hardened” building may use more energy than an ordinary one – to power filters, UPS, monitoring and control systems, standby “spinning” generation, energy storage, redundant systems, etc.

Such a building can also be expected to have improved capabilities, in addition to being able to operate independently of the grid and withstand power system disturbances. A “hardened” building should be able to prioritize loads

- To serve the most critical needs when available power or energy is insufficient to meet all demands, or when a prolonged disturbance or emergency necessitates conserving fuel or energy.
- To reduce demand on the power system by shedding or reducing non-critical loads when reserves are low. This is similar to load control and interruptible load programs.

Another capability of a “hardened” building is to be able to change its setpoints to operate under pre-specified emergency conditions. ASHRAE has defined a Comfort Zone of operative temperature, humidity and air velocity. ASHRAE Standards specify energy efficiency and ventilation minimums while maintaining indoor environment within the comfort zone and a healthy indoor air quality. Under emergency conditions, comfort may have to be sacrificed to a degree, some reduction in ventilation may be tolerated for limited periods, or the HVAC system may forego space conditioning while increasing ventilation. What is acceptable will vary by duration – degraded conditions for 1 hour, 8 hours, or indefinitely – and by type of facility – a hospital is not the same as a grocery store.

This research effort can be viewed as establishing an “EnergyStar-Hardened” program. It will recognize:

- The energy efficiency penalties associated with various types of building enhancements to respond to extreme events
- The additional flexibility and capabilities such buildings should have to reduce energy use on a temporary basis in response to power system or other emergencies.
- The capability to operate under less than comfortable conditions while maintaining essential services and occupant health.
- The provision of on-site fuel or energy to give the facility the ability to function independently for a specified period of time.

Different standards and norms will apply to different types of facilities. For example, *Guidelines for Design and Construction of Hospital and Health Care Facilities* of the American Institute of Architects presents performance-oriented minimum requirements that apply standards (ASHRAE 90.1, 62, and others), norms, and best practices to heath care facilities.

At a minimum this activity should specify the capabilities and performance norms for facilities critical to public health and safety. However, as explained in the Background section, the increased utilization of DER and the higher loading of utility power systems means that more facilities will experience power quality problems that will adversely affect HVAC units under normal operating conditions. Just as there is a value to being able to certify an office building as being an EnergyStar Building, there will be a value in being able to certify an office building as being “EnergyStar-H” and therefore able to function acceptable during anticipated power system disturbances. This broadens the scope and relevance of the proposed program, beyond security concerns, to cover ASHRAE members' often-expressed concerns about how to design and operate HVAC systems and contract for energy under a restructured electric sector.

Expected output:

Performance standards for facilities critical to public health and safety operating under extreme conditions.

Previous work:

- The Energy Star and FEMP programs.
- ASHRAE Standards (such as 90.1, and 62).
- Research proposals of ASHRAE TC 9.12 (Tall Buildings) on prioritizing loads under emergency conditions.
- AIA Design Guidelines for Health Care Facilities

Possible co-funding:

DOE, EPA