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Best practices for zero energy buildings and smart grid integration

Zero energy buildings, renewable energy and the smart grid are key considerations to commercial building design

Learning OBJECTIVES

- Understand the definition of zero energy buildings, knowing that there are currently several approaches to the design of the building and on-site renewable energy sources.
- Examine a snapshot of the current state of zero energy buildings, including the opportunities and challenges facing the integration of the smart grid.
- Discuss how the modernization of the electrical grid, including the development a smart grid, is a key element in the growth of future zero energy building efforts.

When researching building energy efficiency, renewable energy and the electrical grid, industry publications and academic journals will invariably have articles and papers on zero energy buildings and the smart grid.

To eliminate any discrepancies in terminology that may occur in the different publications, we need to use common terminology for ZEB and smart grid. For example, different organizations use nomenclature for ZEB such as zero net energy, net zero energy, net zero, etc. The legacy definitions are not necessarily incorrect; rather they reflect the rapid refinement of technical definitions and nomenclature over the past several years.

To rectify these differences, in 2015 the National Institute of Building Sciences prepared a study titled, "A Common Definition of Zero Energy Buildings" for the U.S. Department of Energy:

"In 2014, the U.S. DOE Building Technologies Office contracted with the National Institute of Building Sciences to establish definitions, associated nomenclature and measurement guidelines for zero energy buildings, with the goal of achieving widespread adoption and use by the building industry."

Similarly, while smart grid is a widely used term, standards are still in development. Because smart grid is a long-range, phased implementation that may mean different things to different constituents, it is not surprising that standards and nomenclature are in a state of flux. But for the purposes of this article, the definition of smart grid is based on the high-level National Institute of Standards and Testing definition:

"… a modernized grid that enables bidirectional flows of energy and uses two-way communication and control capabilities that will lead to an array of new functionalities and applications."

Zero energy buildings in the commercial market

In the past decade, much progress has been made regarding ZEB, and not just research and analysis; many buildings have been designed, built and are operational. The operational facilities offer the opportunity for measurement and monitoring, which is invaluable for the design and construction of future buildings.

As building codes in the United States slowly move toward a requirement for all new building projects to be designed and built in compliance to ZEB standards, the operational data from the facilities will become essential to inform the code officials.

For example, California Title 24 updates , which went into effect January 2020, require all new single-family homes and low-rise apartment buildings to install solar panels to compensate for all electricity used by the building. Also, in 2018 The United States Conference of Mayors passed resolutions that support net-zero building construction by 2050.

Some municipalities require building construction to be "zero energy ready" meaning that the building can be built and operate without the renewable energy component and renewable energy can be added later without significant changes to the building infrastructure.

Definitions for zero energy buildings

Zero energy building (ZEB)	Zero energy campus (ZECa)[1]	Zero energy portfolio (ZEB)	Zero energy community (ZECo)[2]	Zero energy ready (ZER)
An energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy.	An energy-efficient campus where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy.	An energy-efficient portfolio where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy.	An energy-efficient community where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy.	Industry representatives expressed a need to develop a ZER definition for buildings. ZEB was not included in the definitions but it could be added in the future.

[1]The U.S. DOE report did not include an acronym for zero energy campus. To avoid confusion with zero energy community the author developed a name.
[2]The U.S. DOE report did not include an acronym for zero energy community. To avoid confusion with zero energy campus the author developed a name.

These definitions are from the 2015 National Institute of Building Sciences study titled, "A Common Definition of Zero Energy Buildings" prepared for the U.S. Department of Energy. Courtesy: Bill Kosik

According to the New Buildings Institute 2019 listing of zero energy buildings in the U.S. and Canada, projects completed and verified between 2016 and 2019 rose 53% and projects that are in planning or construction rose 79%. These data confirm the idea that zero energy buildings will continue to grow and become a larger percentage of the building stock over time (see Figure 1).

Worldwide, there are many examples of highly efficient buildings that use a fraction of the energy compared to a code-compliant building of similar construction, size and location. While these buildings are ground-breaking and highly efficient, for the most part they rely on electricity supplied by the electrical grid. ZEB are also extremely innovative and efficient and use electricity produced by on-site renewable energy.

A building that is powered by on-site wind and solar resources has a greater degree of complexity, resulting in more design parameters and code requirements. There is certainly a financial benefit for ZEB; while various reports indicate a range of payback periods, many of studies indicate similar financial benefits: utility cost savings of 20% to 50%, a payback between 5 and 10 years and a first-cost increase of 3% to 5%. Certainly, numbers like these can vary widely based on several factors, but there are many examples coming from the design and construction industry that indicate a zero energy building can be a good financial investment.

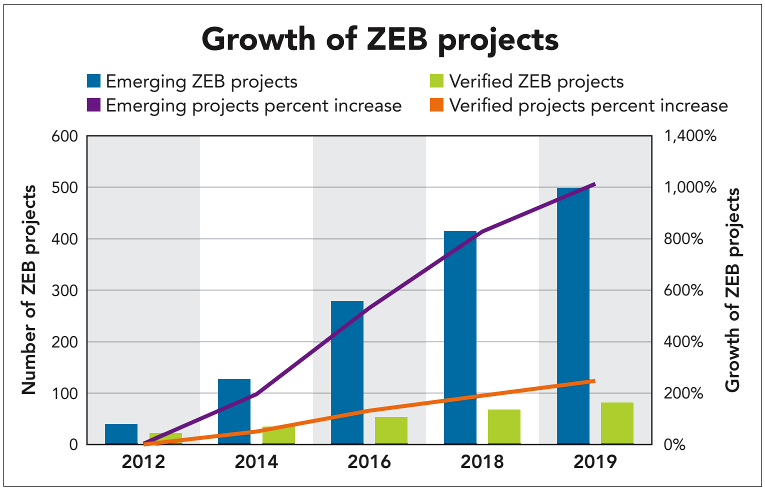

Figure 1: Zero energy building projects are rapidly increasing. Courtesy: Bill Kosik

Zero energy building standardization

As more ZEB are constructed, the lessons learned from the previous projects will gradually close the gap between rock-solid design and construction practices and the difficulties that invariably arise working on a novel and technically innovative project. When the gap is nearly closed, there should be a number of resources that can be made available to professionals assessing the viability of constructing a ZEB.

Open source standards and best practices is one way to safeguard the future success of zero energy building projects; planning, design, construction and operation are all key principles that need to be available to a wider audience. This standardization will encourage closer coordination between manufacturers and builders and allow for a common dialog between code officials and designers. Ultimately, if lawmakers and their constituents understand the value of ZEB to the public and the environment, there will be a good deal more support.

To make this happen, there are important steps that need to be taken:

- The goals of the projects need to be clear to the architecture, engineering and construction industry and to lawmakers, encouraging discussion and engaging in meaningful exchange of ideas.

- The zero energy project must demonstrate (in an easily understandable way) significant reductions in energy use, purchased electricity cost and how the on-site renewable energy source will contribute to the reduction of CO_2 emissions compared to a "business as usual" scenario.

- Using the U.S. Green Building Council's LEED as an example, the building project must have the ability to classified by the industry using a standard method.

- All design concepts for zero energy buildings must be flexible and adaptable as new renewable energy technologies enter the marketplace. Because technologies sometimes have very short cycle times before the next generation is released, care must be taken to avoid obsolescence.

- Accurate measurement and verification of the electricity flows (site to building, site to grid, source to site) is essential in understanding how the buildings operate and to learn for future projects. As the smart grid continues to mature, building owners will have the ability to communicate directly with their energy providers to optimize electricity use and production.

> **Having the ability to use natural ventilation and passive design elements** to reduce solar heat gain and shift the peak cooling load, introduced cost reduction and improved comfort.

Design strategies for zero energy buildings

Design and construction professionals recognize the value working in a team environment where all team members eventually develop a solid understanding of the project goals and holistic design concepts. This team becomes especially important when designing a ZEB; there are elements (such as the renewable energy) that require close coordination and communication that are outside the scope of a "normal" high-performance building.

Among the dozens of technical approaches that shape the building and systems, there are four major design elements for zero energy buildings that form the basis of the overall design strategy; they are all interdependent with each other and must be viewed as a whole:

1. Passive design elements: The most basic ideas of passive cooling and heating are foundational to the successful operation of a zero energy building. But these concepts are not new; they have been used in dwellings worldwide for millennia. The widespread use of and advancements in building design technology, materials and building systems continue to make the fundamental design ideas more viable.

The main theory behind any sustainable design strategy is to work with the climate, not against it. For many decades, commercial office buildings were designed with impervious external envelopes with sealed windows. At certain times of the year, in certain climate zones, this type of construction is vital to minimize heat transfer across the exterior wall assembly and to eliminate air infiltration.

However, having the ability to use natural ventilation and passive design elements to reduce solar heat gain and shift the peak cooling load, introduced cost reduction and improved comfort. The design of a zero energy building is optimized using site weather data including solar and wind data for designing on-site renewable energy systems. At the same time, the passive design components must not have a negative impact on other parts of the design. The final design results in a building that uses as little source energy as possible for the lighting and heating, ventilation and air conditioning systems.

2. Plug and process load: Buildings have a base level of technology (computers, networking gear, etc.) to provide a functional environment for the occupants. LED lighting with occupant sensors, adaptive ambient light level control, high efficiency power supplies and Energy Star office equipment are a few ways to reduce the annual source energy requirement. Minimizing or eliminating these loads saves fan and compressor energy.

3. Efficiency of HVAC systems: Heating, cooling and ventilation systems are one of the highest energy consumers in an office building. Reducing the annual energy use of the HVAC systems will result in a significant energy savings, so there is a priority on energy-efficient design solutions for the HVAC systems. Also, the HVAC and lighting systems have a close relationship with the passive elements of the building design; shading, lighting, thermal mass and ventilation strategies will all provide opportunities to reduce annual energy use.

4. On-site renewable energy: Before renewable energy is introduced into this discussion, it is important to acknowledge that applying the design principles discussed above to a building strategy (passive design, optimal plug and process load and efficient HVAC systems) results in high-performance building that does not have to rely on renewable energy to power the building; it is able to stand on its own as "traditional building" relying on the grid and source energy (albeit using far less energy than a regular code-compliant building). But when renewable energy is brought back into the discussion, things becomes interesting.

Renewable energy generation

On-site renewable energy is the secret sauce for ZEBs. Photovoltaic panels and wind turbines are among the most popular methods for generating on-site electricity. For example, PV panels continue

What is a ZERO energy building?

The current use of the term "zero energy building" does not mean that the building literally has zero energy consumption. In addition to on-site renewable sources, a zero energy building by definition can use energy sources originating from outside the boundary of the building site.

The energy provider in the area will most likely have nonrenewable fuel sources. The times that the on-site renewables cannot match the demand of the ZEB, electricity must be used from the grid. In addition to keeping the electricity load of the building as low as possible, understanding the mix of renewables in the local energy provider's portfolio is an important piece of the puzzle to keeping CO_2 emissions attributable to the ZEB as low as possible.

According to the U.S. Department of Energy, the specific definition of a zero energy building is: "An energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy."

If we look at the on-site renewable energy production used for the ZEBs in their entirety, a distributed generation network model emerges. The magnitude of electricity produced by the individual renewable energy technologies located on the zero energy building site will all vary individually based on building demand, solar intensity, wind speed/direction, etc.

When all of these individual sources of electricity production are fed back into the grid, portions of the demand on the large generation and peaker plants are reduced. By decreasing a small portion of the electrical demand on the fossil fuel driven power plants, the zero energy building owner benefits in two ways: lower electricity bills and reduced CO_2 emissions.

Without the ability to conduct two-way, coordinated communication between the customer and the utility, exporting electricity to the grid poses some challenges. If looked at in aggregate, when the renewable energy systems that support zero energy buildings generate electricity, there are times when the grid doesn't need electricity and, conversely, there are times when the electrical demand of the building exceeds the capacity of the renewable energy source, requiring electricity generated by fossil fuel sources.

There are times where it is not productive for the on-site equipment to export electricity to the grid, especially during off-peak times. For example, if the demand on the overall grid is low, exporting electricity can cause reliability problems with the grid.

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Conversely, there are operational challenges when on-site production resources can no longer meet the demand of the ZEB. This is most common when photovoltaics are used for electricity production. For example, as the sun begins to disappear below the horizon, the utility experiences a spike in electricity demand. Similarly, wind speed and direction are not 100% predictable, resulting in uneven electricity output. As an example, if excess electricity from wind turbines is exported to the grid during the morning hours, the demand at that time is very low and excessive electricity will be exported to the grid, which can stress the grid.

Clearly there are utility-scale PV and wind generation facilities around the world that are producing electricity and have been for decades. The operational difficulties mentioned above are basic examples of scenarios that might become more pronounced as renewable energy technology becomes more widespread.

Also, these points demonstrate the importance of the smart grid to the continued success and proliferation of renewable energy. In any event, it is clear that the design for a zero energy building does not end at the property line. To have continued success in ZEB development, there needs to be a broader dialog with the utilities, municipalities and building owners.

to have a year-over-year reduction in purchase price and the installation methods for the product have become very familiar to contractors and for buildings that have site constraints, PV panels are the best option. One important point: For a ZEB, the renewable energy system has to be located "behind the meter," meaning the use of outside sources of renewable energy (like a local wind farm) can't be classified as site electricity production and is not a part of the renewable energy usage.

In simple terms, electricity flow for a zero energy building has a limited number of paths. But the amount of electricity will vary based on several site and weather factors. As a means of demonstrating the resource consumption and environmental impact from greenhouse gas emissions, site amount of energy used is normalized to source energy.

Electricity generated off-site at a power plant is subjected to energy losses in thermal combustion of fossil fuels, energy losses in transmission and distribution to the building site. As such, the amount of electricity that is generated at the source is higher than what is delivered to the site. These losses are accounted for by applying factors that convert the energy consumed at the site (not including the on-site renewable energy) to the equivalent amount of energy generated at the source. This process is necessary to assess relative efficiencies of buildings with varying fuel types.

ZEBs are a part of a greater ecosystem of different energy-efficiency strategies. As stated earlier, constructing a building that uses less energy and reduces the corresponding CO_2 emissions is one of the core tenets of a zero energy building.

On top of this, there is no shortage of reasons why producing electricity on-site using renewable energy sources such as the sun and wind is notable and forward-looking:

- Fossil fuels have a limited life.
- Combustion of fossil fuels to generate electricity is one of the primary causes of climate change.
- Electricity generated at peak times comes from smaller, less efficient generators, resulting in a greater rate of CO_2 compared to larger, base-loaded generation plants. Some utilities have generation capacity problems and/or aging distribution systems.

Producing electricity on the customer's side of the electricity meter (also known as behind the meter), goes a long way to minimize these issues and over time, potentially eliminate them. Zero energy buildings are a part of a greater ecosystem of different energy-efficiency strategies, including

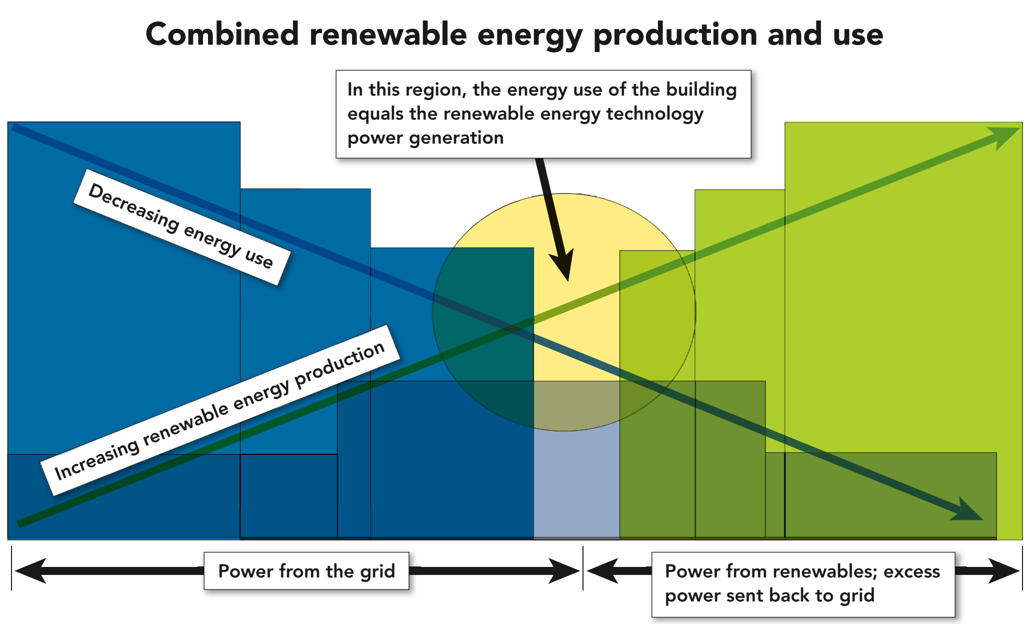

Figure 2: The method of production of energy (electricity) varies widely depending on the renewable energy technology, climate, capacity and end use. This example is to demonstrate the concept of zero energy buildings and how the energy demand of the building interacts with source of energy production. The diagram simulates a technology that is unable to generate energy or generate very little, indicated by the minimum energy production point. It is also assumed that during the day it will generate an increasing amount of energy. Courtesy: Bill Kosik

energy and water efficiency, electric vehicle charging and on-site energy storage.

While these and other strategies may come from different technical domains, they are ultimately implemented for similar reasons — to reduce energy use and the corresponding CO_2 emissions by using renewable energy. The ability to feed power back into the grid relies heavily on the state public utility commission and the electrical distributing company. The rules on net metering are generally regulated and depend on the specific electrical grid. So, unfortunately, there are no uniform rules on net metering; this is a good example of the types of things that need be less complex and less onerous.

Carbon dioxide emissions

CO_2 emissions are attributable to fossil fuel power plants that use coal, natural gas or oil as a fuel. In simple terms, fuel is combusted (the source of the CO_2 emissions) into boiling water, which releases steam to turbines, which drives the power generator. Generally speaking, the electricity that is generated midnight to midnight is considered the base load, where large power plants generate electricity very cost-effectively.

During the day, as more buildings come online and other industrial process are starting, a second and third tier of power generation is brought online to handle the demand that cannot be met by the baseline electricity generation alone. And during certain days and times, especially in the hot summer months, a fourth tier of generation is started.

This is a very basic overview of how a utility operates its generation assets, but it provides necessary background information on source generation, site electricity production and CO_2 emissions.

The utility's capability to adjust source electricity production to match actual end-user demand makes behind the meter electricity production using renewables much more feasible. Depending on the type of technology used in the current source generation plants, some are only suited for satisfying base electricity demand.

But there are power plants such as combined-cycle plants (usually fueled by natural gas) that can cost-effectively ramp up and down to meet the rapid changes in demand that typically occur at the start and end of the peak load. These generators, sometimes referred to as "peaker plants," are able to start up quickly and respond rapidly, but this flexibility comes at a cost — these units are less efficient than the base load power plants, consuming more fuel per megawatt-hour of power produced, resulting in higher CO_2 emissions.

Energy delivery

In developing a model of the electricity flows to and from a ZEB, we need to start by analyzing some foundational concepts which are key for the accurate accounting of CO_2 based on the consumption of site and source electricity emissions.

- **Energy consumed by the zero energy building:** This includes traditional building loads such as HVAC, lighting, appliances, electronic equipment, etc. Interestingly, the charging of electric vehicles counts for exporting renewable energy other than to the grid.
- **Delivered energy:** This is electricity taken off the grid generated by external sources. Delivered energy also includes district heating/cooling, electricity generated by renewable and nonrenewable fuels.
- **On-site renewable energy:** This refers to the legal site boundaries where the zero energy building is located. All means of electricity production must be located on the site such as PV arrays, wind turbines and other renewable energy technologies. If the on-site renewable electricity production exceeds the need of the ZEB, the "extra" electricity can be put on the grid.

All energy consumed by the ZEB will come from the on-site electricity production, the source generation or a combination of the two (with a maximum of 50% coming from source energy).

The smart grid

"Nonwires solutions" and "nonwires alternatives" are terms referring to an overarching portfolio of ideas related to optimizing electricity delivery across the existing grid. These ideas may come from means other than the construction of new transmission lines to relieve grid congestion and improve reliability. In essence, NWS is designed to identify the optimal approach to distribution and transmission enhancement. At the same time planning practices are applied to analyzing the need for power generation projects.

The aim of NWS is to meet public policy objectives, lower costs and/or satisfy reliability goals. Some of the options include:

- Demand response.
- Dynamic retail pricing.
- Distributed generation.
- Energy efficiency.
- Application of technologies to expand the capacity of the system.
- Alternative power dispatch options.

ASHRAE Standard 201-2016: Facility Smart Grid Information Model, published by the American National Standards Institute, ASHRAE and National Electrical Manufacturers Association, provides a roadmap for long-term development of a smart grid. There are dozens of documents published by government agencies and private companies on the advantages of fully integrating renewable energy into the national electric grid. And there are many examples that are in-service and functioning as planned.

However, there is a concern that has been around for many years on how to intelligently interconnect energy sources such as PV and wind to the grid, resulting in the aptly named smart grid. It is anticipated that smart grids will have the following characteristics:

- Resilient to disaster and intentional damage.
- Self-healing networks for rapid deployment after a disturbance.
- Enable new markets.
- Participation of the end-user (customer).
- Power quality to support technology.
- Alternatives for storage generation.
- Optimization of assets allowing for very high operational efficiency.

Currently, the primary means for communication on energy use and energy-efficiency strategies between the utility and the customer is limited to the customer's utility bill and any demand reduction/curtailment agreements that are in place. To build more zero energy buildings that optimize the use of the on-site renewable energy (and reduce CO_2 emissions), all of the challenges and successes that stem from grid interconnectivity must be included in a collective knowledgebase. This type of communication must happen early in the planning phases to understand how the on-site electricity production can impact the grid capacity and many other technical issues.

> **Zero energy buildings are and will continue to be** an essential component to the advancement of site renewable energy technology and the smart grid.

Smart grid standard: ASHRAE 201

Another type of communication that is required consists of two-way data transfer between the end user and the utility. ASHRAE Standard 201: Facility Smart Grid Information Model is an industry-developed and vetted standard that attempts to capture commonalities to standardize the content of the information that a facility manager needs to exchange with the energy provider, to manage the facility.

In turn, energy providers will use the models to develop ways to interact with all different types of facilities using a normalized protocol. Standard 201 defines an abstract information model that will enable facilities' building automation and control systems to manage not only facility energy use (similar to what exists now), but also determining generation sources. This will be as a result of communication with the smart grid and to communicate information about those electrical loads to utility and other electrical service providers.

Ultimately this two-way communication will enable connectivity and optimization of site energy use and source energy generation. The ability to have two-way communication between the facilities' systems and the utility removes the consumer from a position of passive bystander and into the role of active participant.

In 2007 a federal law was passed called the Energy Independence and Security Act (EISA) of 2007. In that law, National Institute of Standards and Technology was given the responsibility for coordinating the development of a framework for smart grid standards. The outcome of the NIST smart grid program will provide guidance on how to connect facilities to the next generation smart grid by developing the technical basis for real-time pricing, distributed energy resources, demand response, distributed generation, energy storage, electric vehicle charging control and consumer access to energy usage information.

This is the type of program that, over time, will enable the full potential of renewables used in zero energy buildings; the bidirectional exchange of real-time data and analytics is a crucial component to synchronize the actions of the utility and end user. In certain scenarios these actions will be automated allowing for a rapid response to address potential grid instability or reliability.

Although details on planning and future development of the smart grid are beyond the scope of this article, the successful growth of ZEB projects is very much dependent on the smart grid. The independent and collaborative organizations responsible for the coordination, control, monitoring and operation of the electrical power system are playing a major role in this endeavor.

And because these organizations encompass multiple states, standardization and uniformity is critical for planning and implementation. Understanding the potential of reducing the demand on the electric grid, as well as decreasing CO_2 emissions from the built environment, ZEB are and will continue to be an essential component to the advancement of site renewable energy technology and the smart grid. cse

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White Paper CONNECTION

NEC 2017 Update: Emergency Generator Set Start Signal Integrity

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EMERGENCY GENERATOR SET START SIGNAL INTEGRITY

White Paper

By Rich Scroggins and Ravi Thapa

NEC 2017 has new requirements for emergency generator start control wiring between the transfer equipment and the emergency generator. This paper discusses the new requirement and wiring installation to meet the new requirement.

A Generator engine is typically started with normally open contacts or normally closed contacts at the transfer equipment know as remote start contacts. When the loads require generator power the remote start contacts are closed to start the generator engine. The start signal contacts need to be connected between the generator and the transfer equipment. Previous code installations requirements generally did not require monitoring of the remote start signal connections. If the remote start circuit is broken, disconnected or shorted then there was no means to indicate it to the operator which results in power supply failure during normal source failure. Monitoring and alarming the integrity of start signal means the operator could take proactive approaches to fix the issue.

NEC 2017 NEW REQUIREMENTS FROM ARTICLE 700.10 (D) (3) GENERATOR CONTROL WIRING

"Control conductors installed between the transfer equipment and the emergency generator shall be kept entirely independent of all other wiring and shall meet the conditions of 700.10(D)(1). The integrity of the generator **control wiring shall be continuously monitored.** Loss of integrity of the remote start circuit(s) shall initiate visual and audible annunciation of generator malfunction at the generator local and remote annunciator(s) and start the generator(s)."

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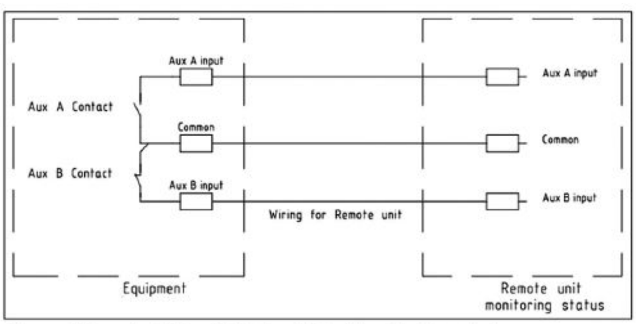

Figure 1: Remote start and start signal integrity wiring for a single transfer equipment and an emergency generator set.

Previous code installations requirements generally did not require monitoring of the remote start signal connections. If the remote start circuit is broken, disconnected or shorted then there was no means to indicate it to the operator which results in power supply failure during normal source failure. Monitoring and alarming the integrity of start signal means the operator could take proactive approaches to fix the issue.

The original language offered in the new code required the remote start signal to be continuously monitored. Further, the code requires the generator(s) to be started on loss of integrity of the remote start signal to ensure emergency applications have a healthy backup source.

A Tentative Interim Amendment was submitted and processed by the National Electrical Code Panel 13 and the NEC Correlating Committee, and was issued by the Standards Council on August 14, 2018, with an effective date of September 3, 2018. The amendment on the code language has removed continuous monitoring and visual/ audible annunciation requirements. The new code language requires monitoring for broken, disconnected or shorted wires only and the generator(s) need to be started on loss of integrity of the start signal.

Integrity contacts circuits discussed in this paper could be used to satisfy the new NEC 700.10 requirements to monitor generator remote start signal for broken, disconnected or shorted wires.

Download the paper at: https://bit.ly/2AoUwLm

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