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Building Electrical Power Distribution Efficiency and Performance Optimization by Designing Resilient Systems

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Abstract

The building power systems are often exposed to losses due to inefficiencies arising from various sub-systems. The major sub-system within a building includes electrical, mechanical, and plumbing. Although less common for small and medium-sized buildings, there is a large process equipment when supporting manufacturing or small operations within. One such example is when a building is operating to support systems for the ventilation power and controls for large outdoor enclosed spaces such as roadway and railroad tunnels. The problem statement here is to solve the issues related to inefficient lighting and power systems for a building by eliminating the losses from either poorly designed and installed power distribution, lack of maintenance, or need to address practices in building energy management systems. The research dives into exploring the power systems in a typical building and then explores viable solutions when reviewing some of the energy standards, practices in maintenance and installation of the equipment. However, the emphasis is not to review the standards and recommend the changes. The study will recommend improvements based on currently installed systems in lighting and power by utilizing current energy management systems which integrates renewable energy and zero emission systems. A typical power system designed to address energy efficiency and power resiliency was developed after addressing some processes and methods to operate commercial buildings using a controller operating at stringent requirements.

Keywords: Power distribution systems, energy optimization, renewable energy, energy efficiency, energy management systems

INTRODUCTION

Building systems comprise of major sources of emissions by both their usage and equivalent carbon emissions from energy consumption [1, 2]. This has resulted in research scholars to explore energy efficiency optimization from time to time. Since, major commercial buildings are either retail, office, multi-family residential units, or process spaces, the equipment inherently within the buildings operates at low to medium voltage power to supply electrical, mechanical, and plumbing equipment. In most cases the majority of the power is utilized for space heating and cooling. Depending on the geographical location of the buildings, the energy consumption varies, but in general, buildings require a significant amount of electrical energy to run the systems. More recent advancements in energy management systems with the inclusion of renewable energy or distributed generation systems have resulted in more power resiliency and energy independence from conventional power generation systems. Many sources have actively substantiated the arguments that energy systems when optimized will result in reduced carbon emissions and improved well-being of both building occupants and general public.

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Whereas the essence of improving the way electrical energy is utilized is not to resort to curtailment of using certain types of systems, but to switch to alternate means. For example, a conventionally used water heating system may be replaced with a solar water heater on a commercial scale. Similarly, with rising electrified transportation systems, many commercial buildings have readily available energy storage from the occupant owned electric vehicles [2].

The use of dedicated systems to address the power resiliency known from existing literature using automated transfer switches to the distributed generation systems during loss of power or use of tied systems from roof-top solar continues to remain a feasible solution when energy crises loom [3]. Many countries have explored the need to isolate the towns and develop them as a separate system operating on its own microgrid system independently operating from grid integrated system. However, some developing countries rely on curtailment of certain types of systems within the building such as space heating to limit the heating costs. Although the topic of replacement of existing lighting systems with energy-efficient LED systems continues to have widespread adoption, there are many buildings across the world that lack such application. This indicates even with available solution for improving lighting systems, there are many factors that are limiting their widespread use. These factors are: high cost of installation, lack of local governing bodies for compliance, lack of building users interest, subjective visual comfort, and so on. Figure 1 shows a cluttered electrical wiring at typical outdoor environment in a populated city.

Figure 1. Cluttered electrical wiring.
Source: Google Maps.

The mechanical systems relating to heating and cooling are often certified for energy efficiency but they may be energy in-efficient due to several factors such as poor maintenance. For example, deteriorated systems from corrosion or electrical stresses can result in equipment consuming more energy. Additionally, in-appropriately installed systems can also cause increased energy consumption. For example, an electric water heater rated at 240 V power supply rating would be inefficient when operated at 208 V power supply. Additionally, the ideal scenario at power distribution level is to step-down the voltage [4]. However, due to meeting the equipment power voltage ratings, many system upgrades have step-up transformers at distribution level. The equipment at the manufacturing facilities are designed to achieve up to 99% efficiency from operation. However, there is a lack of literature that validates any such practices in improving the efficiencies from installation of the power systems. For example, the engineering standards do govern the ideal ratings for the overcurrent protection devices and installed power conductors. However, there is no such practice wherein at design the focus is around achieving minimized losses from distribution system within the building. Therefore, some solutions such as installation climate controlled electrical rooms, raceway systems, and installation of renewable energy systems could become a viable solution, but exact use case depends on the type of building and the materials used for installation [4]. Depending on the types of commercial buildings the current provisions for energy conservation in building standards will apply starting from IECC, ASHRAE, or IBC [5]. The systems may be optimized for:

- *Energy Efficient Lighting Systems:* Both the International Energy Conservation Code and ASHRAE allow the users comply the requirements for the controls to limit the usage based on occupancy and limit the wattage per square feet for the luminaires chosen.
- *Energy Efficient HVAC Systems:* ASHRAE allows selection of the HVAC units in compliance with energy standards, and equipment are often selected for the energy star rating for complying the set energy efficiency requirements.
- *Energy Efficient Renewable Energy Systems:* Renewable energy systems are often known to increase the burden on the power grid due to the addition of harmonics and intermittent power generation capabilities. An efficiently operating system that balances the generation profile over time is most suitable for a given application.
- *Energy Efficient EV Charging Systems:* Electric vehicles have continued to be researched and optimized from both the vehicle dynamics and battery storage prospective. However, there exist some major concerns regarding the loss of system power from power delivery using charging units and vehicle battery management systems. This leads to the exploration of the options wherein the system efficiencies from charging could be contained within a reasonable limit as approaching unity.

This study is organized into sections, namely: Introduction which goes over the basic literature and overview of how electrical systems look like for a commercial building by engaging the need of the exploration of the topic on attaining energy efficiency of commercial buildings. Methods go into the in-depth application of principles of energy conservation derived from author's understanding of the engineering standards and proposed innovations. Conclusion and discussion further highlight the major takeaways from this research by documenting any possible limitations that can help future researchers to advance this research work.

METHODOLOGY

In this section, the attainment of process to establish an energy efficient system for a typical building of 10,000 ft^2 is explored. Figure 2 shows how internal processes within the building may result in optimization by using a controller to stay off-grid under normal conditions. The building loads are primarily roof-top HVAC units, fire pump, water heaters, sewer pumps, lighting, specialized systems such as data equipment, fire alarm systems, and so on. The building mainly comprises of spaces categorized as: Common Lobby Area, Banquet Hall, Office Spaces, Vestibules, Attic, Electrical and Mechanical spaces, and so on.

Optimization Using Application of Each of the Energy Efficient Systems

The system as shown in Figure 2 has been optimized by the use of energy management controller. The readily available systems for the building management systems often become suitable for this application. However, this study proposes that this energy management controller operates under normal conditions without drawing any power from the grid but allowing back-feeding into the grid. Additionally, the power deficit within the microgrid system automatically cuts the power to some of the non-essential systems. For example, certain sockets within the system or the heating loads may get turned off when there is no surplus power available from the microgrid system operating for the building. This is a strict regulation which may require many policy changes to address its implementation when using microgrid systems. This continues to be a topic of discussion both at research level and when large scale implementation is concerned.

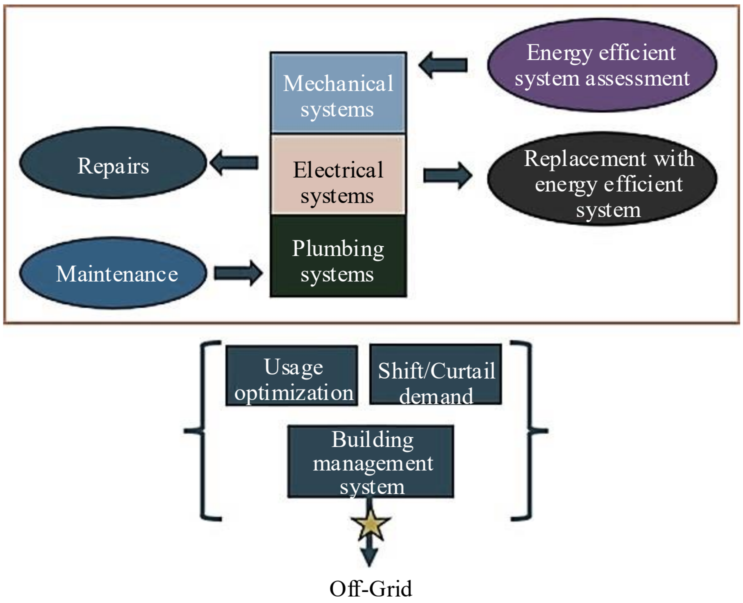

Figure 2. Commercial building systems.

Resilient Power System Overview

The system is intended to provide power for a commercial building of space more than 10,000 ft^2 with dedicated power system operating from battery energy storage system and electric vehicle plug-in point to improve the power resiliency of the current system along with optimization of the energy efficiency obtained by incorporating a local power generation system which in addition includes an on-board standby generator. The system is intended to work at an operating voltage of 220 V single-phase at 200 A of electrical service [6]. The electrical loads are primarily serving illumination luminaires, unit heaters, split AC units, computer devices, camera systems, water pumps, and instantaneous water heaters. The configuration of the system is to ensure operation of the system with battery energy storage system and battery plugin point via an inverter under normal power loss and operating conditions. However, when there is a lack of available battery levels the switch can be switched to stand-by generator as shown in Figure 3.

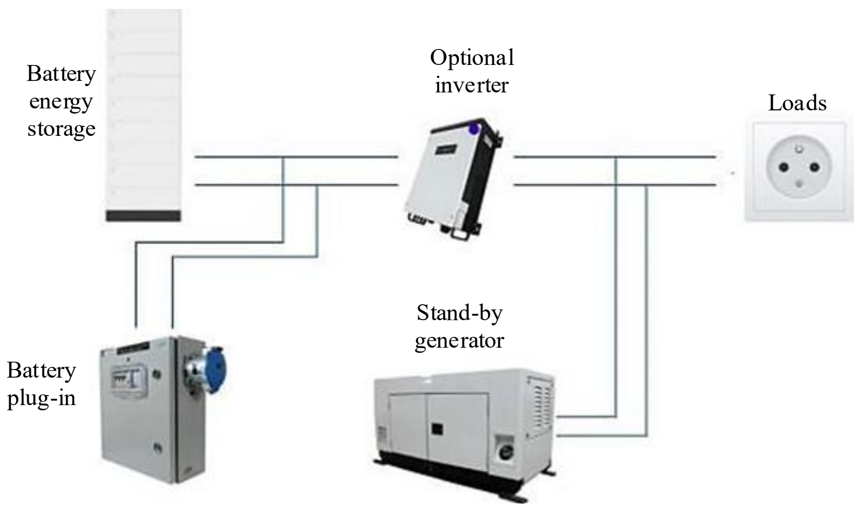

Figure 3. System diagram.

Components

The major components of the system are enumerated in the section below:

- *Electrical power bus:* This bus is embedded in-to the concrete walls and encased in PVC conduit of trade size 1 in. The ampacity of the conductors matches with 50 kVA rating. The conductors and PVC conduit system are supposed to be not exposed to any wet conditions unless otherwise for the outdoor battery plug-in points where the weatherproof enclosures may provide the additional protection from water ingress. The entire scope of the installation must include an environment less prone to any moisture and water ingress.
- *Battery Storage System:* The battery energy storage system includes five (5), 220 V, 10 kVA units located within an electrical room which is climate controlled using a split AC unit system. The storage system being located indoor and climate controlled ensures the system operates at optimal temperature rating without harming any of the power electronics and electrical components. The permissible temperature potentially improves the life expectancy of equipment as well.
- *Sockets for EV Battery Plug-in:* A receptacle device (socket) of ratings supporting 220 V, DC is located at outdoor wall under a covered shed with a weatherproof enclosure to allow plugging-in of an EV battery. The socket comes in various different sizes and configuration; in this case, the intent is to obtain the sockets and dedicated to draw power for any plugin device. For example, most of the split AC units are capable of being powered from a socket, whereas some specialized hardwired equipment requires engagement of the socket mechanism to take advantage of the proposed system.
- *Sockets for Building Loads:* Individual sockets for building loads for lighting and devices rated at 24/48 V DC supply distributed to allow redundancy when not operating a stand-by generator. The mobile chargers, computer devices, and any miscellaneous loads may be provided with a socket; they may or may not have a grounding connection. The selection of the grounding point is governed by the ampacity of the current drawn and the severity of any hazard from the rated devices.

For clarity purposes, some of the elements that are inclusive are automatic transfer switches operating to switch between normal and emergency power, and power panelboards located at the load and generator ends. These components are designed in accordance with the rating for the chosen generator and support the building loads by the power panelboard. Usually, a power panelboard is installed for the system at the service entrance from the utility company. The power panelboard main breaker is equipped to allow protection from any overcurrent loading conditions. The molded case circuit breakers are equipped to contain the hazards from any circuit interruptions. Additionally, the generator is equipped with a generator panel with overcurrent protection devices to contain any faults in the generator bus. This leads to adding elements mainly that improve the system performance when operating in stressed conditions which is the mechanical cooling system for the engine generator provided by the manufacturer and load banks that are used to test the operational condition on a timely basis.

Materials

The list of the materials is based on the general understanding of the requirements for implementation for a commercial building. However, market available products may be obtained as close to matching the items shown in Table 1. Other areas to focus on when obtaining materials is governed by its installation using safe practices. For example, the installation must be free of any entry of water or fluids into which can disrupt the safety compliance because of unlisted for wet locations [7, 8].

Electrical Safety

Safe operating conditions for electrical equipment are not only governed by the design considerations but also its installation and the way it is maintained over time to draw its useful life without any hazards or failures. Usually, the engineering standards are revisited over a regular period to ensure the design standards, when followed by during system design stage, ensure increased safety [9, 10]. However, many practices, especially in the installation and maintenance of the equipment, result in failures. To increase the level of safety, some systems are designed with oversized equipment and too many safety factors which result in either increased system losses from power consumption or maintenance. For example, some larger generators are expensive to maintain whereas many small sized generators are cheaper to purchase and maintain. So, many aspects of the mechanical systems where-in the oversized AC units result in increased power consumption. Additionally, many heating loads depend on selection of unit heaters for space heating purposes. However, electrical power conductors with thicker strands may result in varying resistance per unit length and so would the terminal blocks and buses in the enclosed switchgears. Nonetheless, the equipment safety from use is often focused on the arc-flash hazards for personnel safety and the containment of any potential damage to the electrical equipment from short-circuit currents during faults.

Table 1. Materials.

S.N.	Item	Description	Quantity
1	Power conductors	Used within the building systems	2130 m
2	Power sockets (220 V)	Used for loads equipment	50 Each
3	PVC Conduit	Used for embedding into the concrete walls for power conductors	915 m
4	Stand-by generator	Used for backup power and located outdoor	1 Each
5	Automatic transfer switch	Used for transfer of normal to emergency power	1 Each
6	Inverter	Used for converting DC power to AC	1 Each
7	Battery storage system	Used for storing power from renewable energy systems (solar or wind)	1 Each
8	Battery plugin socket	Used for plug-in in electric vehicle battery	1 Each
9	Miscellaneous items	Used for supporting any other electrical requirements	1 Lump Sum

Advantages of the System

The commercial building in this case sees and increases power resiliency from both battery energy storage system and battery plugin point in addition to the standby generator backup [11, 12]. Both these additional elements reduce energy bills when added with either a roof-top solar PV system or a small wind turbine. Some of the readily available products from the commercial market allow ease in availability of the system components thereby reducing the burden of the customer in ordering any customized equipment suitable for the power needs. When some of the newer loads and opportunities come in from the electric vehicles and from storage from batteries, this system has proposed various methods to ensure that the integration is possible. Subject to policies and procedures, many of the vehicle-2-grid integration systems require smart controllers and working closely with the power utility company for not disrupting the power quality from the undue addition of power electronic components that cause harmonics.

DISCUSSION

The scope of this work relies on studying the existing literature and available products in the market that can support systems operating to maximize the energy savings and simultaneously increase the system power resilience. In days to come when the energy crisis would lead to increased dependence on renewable energy, the choice of available options for commercial buildings in installation of the renewable energy systems could become challenging because of the presence of utility scale large solar farms or wind farms. In this scenario, the operation of the local solar PV system mounted to roof-top or ground mount near the close proximity would be mainly governed by fact that reduced distance from generation source to the loads increases the system efficiency. However, the overall cost implications from such small systems operating as microgrids independently off the grid poses threats to the fundamental principle of being integrated together to increase the power resiliency of the whole larger system.

CONCLUSION

The electrical systems for commercial buildings were explored in this research study. Various process-related aspects for maintaining and upgrading the mechanical, electrical, and plumbing systems were explored with recommendations on how to plan and operate the microgrid systems using a set guideline for operating the building energy management controllers. Many modern power systems are designed to accommodate any distributed energy generation, but literature suggests that there are still opportunities available to explore the options of integration of renewable energy by varying the modes of operation. Although standards have assisted with ensuring power systems operating at maximum safety, the need to assess the size of the equipment chosen was presented when exploring any inefficiencies inherent from oversizing mechanical and electrical equipment. A 10,000 ft^2 and larger commercial building electrical systems were optimized using the intent presented in the methods section and therefore power resiliency was added with battery storage along with standby generator.

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