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A Literature Review of DC Microgrid for Building

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Abstract – *DC Microgrid is becoming an attraction in the present day. There is an increase in the implementation of renewable energy for electricity generation, which usually produces DC power supply. On the other hand, it is quite evident that native DC loads are growing. Electronics and emerging technologies such as compact fluorescent and LED lamps, and variable frequency drives (VFDs) that use DC are becoming commonplace. This issue is becoming an idea to adopt the DC grid, especially in buildings, instead of conventional AC, to bypass the loss at converting from AC to DC. The DC microgrid implementation for buildings has its advantages, such as efficiency, simple, and easy to build. However, the DC microgrid for building also has its challenges for implementation, such as lack of ecosystem and standard, also technical challenges.*

Key Words: DC Microgrid, Buildings, Native DC Load, Efficiency, DC power system

1. INTRODUCTION

The conventional electrical systems are dominated by AC power. The reason for the success of AC (Alternating Current) over DC (Direct Current) was the invention of the transformer, which can easily convert power from the transmission to distribution systems at different voltage levels. An advantage of DC over AC has been recognized for long-distance power transmission because high-voltage DC lines suffer from lower electrical losses and provide better control of power flows [1].

However, the advantages that AC systems used to have are no longer applicable, as DC/DC converters can also step-up or step down the voltage efficiently. Therefore, nowadays, DC systems are more efficient and economical-wise than they were before. So, the DC microgrid is the most logical solution for nowadays trends in every aspect of the present electricity system model. [2]

It is quite apparent that native DC loads are growing. Electronics are everywhere, compact fluorescent and LED lamps are ubiquitous, and also, many emerging technologies, such as variable frequency drives (VFDs) that use DC are becoming commonplace. This trend is so clearly not only because of the attractive capabilities, efficiency, and reliability of these devices but also because public policies motivated by energy efficiency and related goals are reinforcing the trend. Likewise, also stimulated by subsidies, the deployment of PV, a DC source especially amenable to building scale systems close to loads, continues to grow exponentially.[3]

Until now, buildings still use AC conventional grids. However, as mentioned before, almost all the loads on these buildings are native DC. An illustration of the inefficiency of the existing conventional AC system can be seen in Fig- 1.

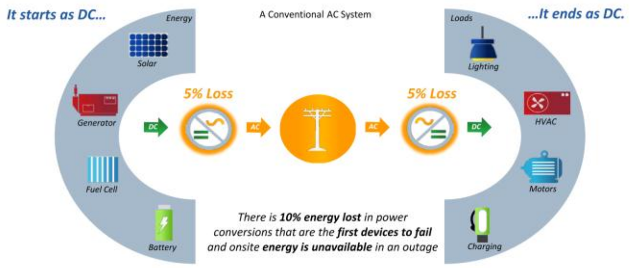

Fig- 1: Conventional AC system illustration [4]

There is about 10% energy lost in power conversions in a conventional AC system. A double inversion from DC to AC at the system end and then from AC to DC at the load end in a conventional solar system can only cause unnecessary complexity and energy loss [5].

The rising demand for implementing renewable energy resources is bringing back DC into the energy distribution frame. DC grid is more accessible in integrating renewable sources into the grid in such case. Most loads at the utilization terminal these days are DC. So, many types of exploration have been going on DC systems and their prospective utilization in building applications [6]. DC power grids offer more efficient electricity distribution with less conductor material compared with AC grids [7]. Hence, DC grids offer both cost reduction and sustainability features.

There are many research and application about hybrid DC/AC microgrid in [1], [8]–[10] which is a more viable option than the full DC microgrid. However, there will be more complexity in control of the conversion. On the other hand, in implementing DC microgrid, the existing devices in building such as heating, ventilation, and air conditioning (HVAC), lighting, power socket, etc, still have conventional AC socket and utilizing AC/DC conversion included in the devices [11]. In [12], the DC microgrid improves the percentage of PV energy that performs useful work to approximately 97% from a baseline value of 90%. The DC microgrid supply loads with less energy loss in conversions, significantly increasing energy efficiency compared to a traditional AC system.

However, this paper will discuss the overview of a full-DC microgrid in building its advantages, attraction, and challenges.

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2. THE ATTRACTION OF DC MICROGRID IN BUILDING

The US Department of Energy definition of a microgrid is an integrated energy system consisting of distributed energy resources (DER) and multiple energy loads operating as a single controllable entity in parallel to or islanded from the existing power grid. [13]

However, in [14], the DC microgrid is defined as an electrical system that can efficiently distribute, consume and potentially create and store Direct Current (DC) electricity to power a wide variety of electrical devices in and around buildings when connected to a utility grid or as an island.

The energy landscape is leaning towards DC rather than AC. This statement can be proven as there are many technological developments, such as:

- More native DC building equipment
- More DC-based distributed generation
- The declining cost of on-site storage and EV charging
- Advances in power electronics
- Evolving DC power standards
- Better power quality

DC microgrid for a building is an interesting option for buildings to connect natural DC power sources. Those DC power sources are photovoltaic power systems with DC loads like lighting, IT systems as well as speed-controlled electric motors of heating, ventilation, and air-conditioning systems. [6]

In every DC microgrid, there will be:

- DC Power Sources
- DC Power Distribution Networks
- DC Devices/Loads
- Controls/Monitoring

2.1 Advantages of DC Microgrid Building

There are complexities of an AC building design. The AC systems architecture requires independent building systems and require to separate the wiring or wireless controls for data. The separation is utilizing a multitude of power conversion devices and switches. Also, AC systems do not work in an outage.

On the other hand, a DC building grid, the existing highest energy-efficient solution available using a 380Vdc architecture where on-site generation directly supplies the building loads and data networks. Also, it is a reliable solution for retrofit and new construction facilities that is resilient when the grid fails and is cost-effective from day one and throughout the 25-year system life. [4]

The design of DC building is a system architecture that integrates building systems using existing wires for power and data with a single point for bi-directional power conversion without the need for switches, which make it simpler than AC building.

The LED luminaires of the AC grid system are the same as of the DC grid system; however, the LED driver includes an AC mains rectifier and a power factor correction circuit (PFC) additionally. This rectifier and PFC are usually called an AC LED driver. However, it has only 80-90% efficiency [4] with power conversion components that generate heat and frequently fail, which increases the need for replacements.

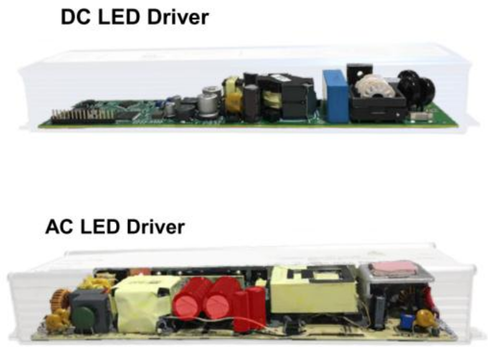

Fig- 2: DC and AC LED Driver [4]

On the other hand, LED luminaires are native DC load so that the DC LED driver is more efficient and reliable 98% efficient with no AC/DC conversion components resulting in cooler operation, extended product life, and fewer replacements.

Apart from integrating more renewables, DC microgrid concept has many other advantages and applications. For example, different DC microgrid architectures can facilitate the design of ultra-available power sources for critical loads, such as hospitals, security units, data centers, etc. [15]

The DC microgrid is also resistant to disasters. Even under conditions where electric power and fuel are not supplied from outside, DC microgrid can have electric power sources. At the time of the power failure of the commercial grid, the DC microgrid works as an independent power source that disconnected from the commercial grid. Since power from regular distribution lines supplies to loads, exclusive lines for emergencies are unnecessary. In such a situation, in order to continue the independent or island operation, the power supply needs to be regulated; however, people who live in the same community would cooperate to make the best use of the limited power. [16]

The status quo of the existing common building of AC conventional is illustrated in Fig- 3.

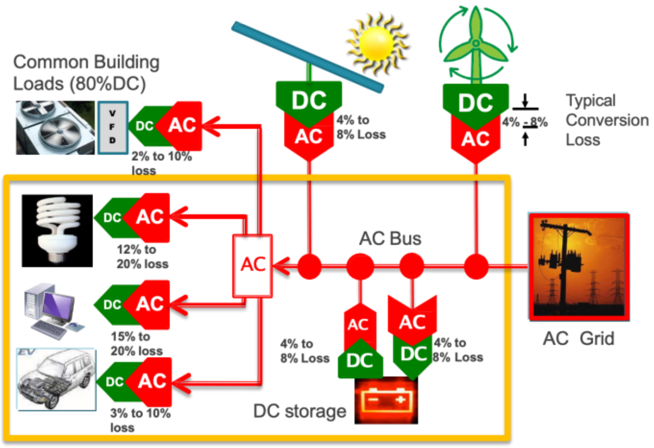

Fig- 3: Status Quo of AC Grid [14]

However, the better way is to adopt the DC grid, which is illustrated in Fig- 4. The DC grid will have:

- Higher Efficiency
- Minimal Conversion Loss
- Lower Operating Expense
- Safer
- Fewer Components
- More Reliable
- Less Real Estate
- Reduced Carbon Footprint

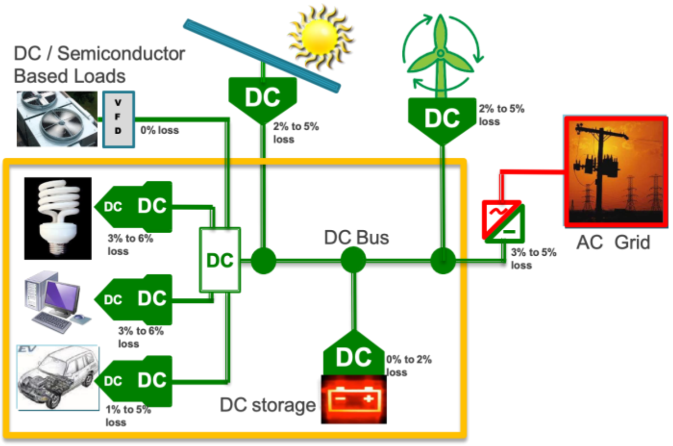

Fig- 4: A Better Way of DC Grid [14]

DC microgrid has the advantages of high stability, simple control, easy to be accessed to the power supply, and easy to be implemented. The DC microgrid structure is simple, and the phase and frequency are not considered when the immense power grid is connected, and it only controls the voltage and active power on the DC bus. This will reduce the difficulty of control; it can maximize the use of distributed energy and save power electronic devices. [17]

2.2 Trend toward DC Building

The trend toward the use of DC devices has been increasing for decades. Datacenter growth alone approaches a compound average annual rate of nearly 30%. Also, more than 80% of the electricity used in office buildings passes through power electronics and experience one or more conversion between AC and DC electricity. [11]

Consequently, if the amount of DC loads is increasing, and so is the DC generation in general, but mainly the case of household electricity production, avoiding the DC/AC/DC conversion losses will be possible.

A typical rectifier and power-factor-correction circuits are considered to operate with an efficiency of 97 %. Up to 2/3 of these 3 % loss are potentially saved when supplying building energy consumption directly from DC solar power, including lighting, electrical building heating, and cooling systems, as well as in IT systems. About 1/3 of a building energy consumption may still be supplied from utility AC grids that finally generates losses in rectifier and PFC converters. [6]

The reduction in power electronic conversion equipment makes the overall system more efficient, reliable, and will reduce maintenance costs. The use of a separate DC bus provides a built-in mechanism for operating critical DC loads during grid outages (to the extent that energy is available from local DC generation or storage) without requiring a mechanical transfer switch. [12]

From the utility perspective, the DC architecture reduces the size of inverters required to export excess PV energy, thereby mitigating the potential impact of PV variability on the grid. Furthermore, DC-based battery storage can be much more efficiently connected to a DC grid, which is the most cost-effective way to reduce PV intermittency.

There are potential cost savings of DC building grids. The cost includes installation cost, energy cost, and operation/maintenance cost. For a 25-year lifetime cost, the DC building will be lower by about 30%. [4]

DC power grids in buildings can achieve potentially higher efficiency advantages in the order of 5 % compared with the measured 2 %, as explained in [6].

The roadmap for DC Systems is illustrated in Fig- 5 which shows that DC power systems will be the future of electricity distribution and transmission.

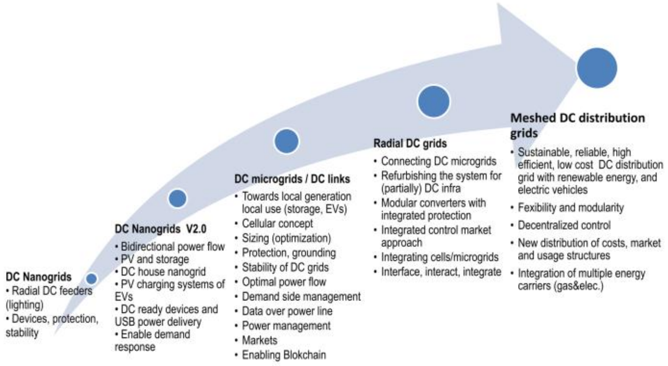

Fig- 5: Roadmap for DC Systems[18]

On the other hand, the DC building technologies market shows growing significantly, as shown in Fig- 6 as representation in the US.

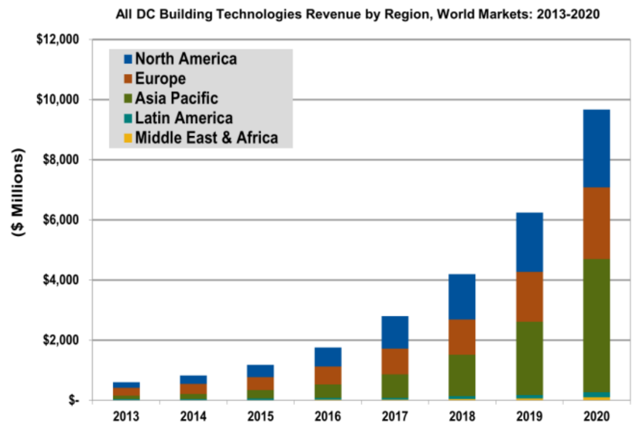

Fig- 6: DC Building Technologies Revenue [4]

3. THE CHALLENGES OF DC MICROGRID IN BUILDING

As mentioned before, DC microgrids have many potentials and advantages. However, there are several challenges that still a major issue in implementing the DC microgrids in buildings fully.

The use of DC power itself is not without its challenges. these fall into five major categories [11]:

1. lack of standard for application and equipment in the DC system
2. lack of shared and common understanding and basic application knowledge of building distribution-level DC
3. differences in safety and power protection device application
4. lack of a robust ecosystem to support the use of dc in building-level electrification
5. An unclear pathway for migrating from AC-centric power distribution to DC-inclusive distribution schemes.

3.1 DC Standards

The first three challenges are being addressed with increasing resources by such standards and trade organizations as awareness of and interest in the potential benefits of DC power use increases, so do the resources each of these organizations is willing to dedicate to resolving these challenges.

There are more than 80% of the electricity used in office buildings passes through power electronics and experience one or more conversion between AC and DC electricity. However, we do not have comprehensive standards for how best to generate, distribute, and to utilize DC power, which is the form of electricity of the devices in buildings use. Such a standard could provide the opportunity to reduce and eliminate unnecessary power conversions. Also, those standards will help simplify and improve the reliability of the electronic equipment involved.

Standards and codes play critical roles in moving us toward improved energy use. Organizations such as the National Fire Protection Association (NFPA), Underwriters Laboratory (UL), National Electric Manufacturing Association (NEMA), and newer ones (including EA) are working together. They are addressing critical issues for alternative energy, including DC microgrid distribution systems and electric vehicle charging as well as DC distributed electricity storage, natively DC generation systems, and other new dc electrical uses. [11]

However, there are several existing DC systems compliant with code and safety standards, such as [4]:

- NFPA 70 (National Electric Code) compliant
    - All present electrical building codes that apply to AC systems also apply to DC systems
    - 2017 NEC includes a new Article 712 that provides additional clarity on certain aspects of a DC microgrid
- UL compliant
    - All DC components can be UL listed with their respective UL standards
- IEC compliant
- EMerge Alliance
    - Developing open standards for DC microgrids in buildings
- Safety
    - Ungrounded, high resistance grounded, or low resistance grounded systems

On the other hand, every single piece of load devices in commercial buildings have AC conventional power supply standard. There are always AC to DC converter inside the devices. Until now, there is no DC standard for devices. However, this issue is understandable because the outlet for these devices using AC standard outlets.

There are key application areas for standardization of DC microgrid utilization in buildings include [11]:

- Interiors and occupied spaces where DC lighting and control loads are dominating
- data centers and central telecom offices with their DC-powered ICT equipment
- Outdoor electrical uses:
  - electric vehicle charging
  - outdoor LED lighting
- Building services, utilities, and HVAC with VSD and electronic DC motorized equipment.

3.2 Technical Challenges

The DC microgrid system is having several practical challenges in distributing a regulated power supply. The DC microgrid, which supplying low DC voltage, will have higher currents. This condition will require high gauge cables, which leads to an increase in overall losses. Thus in order to reduce the losses and save the installation cost, the DC microgrid voltage must be sufficiently high enough.

Nowadays, many companies are considering running their products on DC. Along with the increase in the usage of electronic devices, which are native DC load, makes it is necessary to study the voltage levels required. This study was conducted to establish the optimum voltage level in the distribution system of a building or the DC/DC converters that will be required.

The selection of the bus voltage is a challenge itself. There are issues of having one or multiple voltage levels. Higher voltage levels lead to lower currents; therefore, lower conduction losses, whereas the risk of electric shock is higher than when lower voltage levels are chosen. However, the conduction losses when having lower voltage levels are higher due to rectification. [2]

On the other hand, to efficiently adopt full DC microgrid applications, a suitable size energy storage unit and a two-way inverter are needed to ensure stable bus voltage and continuous power supplies. So that, for existing commercial building applications, DC and AC hybrid system would be a more suitable model. [19]

On the safety aspects, DC microgrids require different switches, connectors, plugs, fuses, and circuit breakers than AC grids that suppress arcing when disconnecting live DC currents. The need for power switches for DC grids is also reduced if electric appliances have control interfaces for the connection to a building management system. The switching of appliances is simply realized utilizing controls. [7]

4. CONCLUSION

The DC microgrid for a building has many advantages, such as efficiency, simple, easy to control, reliable, etc. However, to adopt a full-DC microgrid, including to bypass the conversion AC to DC at its load, there are several challenges. The challenges of adopting DC microgrid for buildings are there is a lack of ecosystem and standard, which makes only a few manufacturers that produce DC devices. On the other hand, the existing conventional AC distribution system is still considered reliable. However, the DC microgrid is in the near future, full-DC microgrid implementation for buildings will have more efficiency, controllability, and reliability.

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