

Analysis of Electric Power Architectures to Improve Availability and Efficiency of Air Conditioning Systems

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Overview

- **Introduction:** Issues with air conditioning (A/C) systems
- **Electric power supply architectures for A/C systems:**
 - Traditional architecture
 - Availability
 - Efficiency
 - ac vs. dc
 - Options derived from the traditional architecture
 - Architectures using distributed generation technologies
- **Conclusions**

Introduction

- A/C systems are an essential part of information technology (i.e. datacenters) and telecom infrastructures.
- There are two long-existing problems for A/C systems:
 - Low energy efficiency
 - Low availability
- **Energy efficiency facts:**
 - In datacenters, the A/C system consumes between 30 % to 50 % of the total datacenter power consumption. Yearly electricity cost for an 1 MW datacenter could reach U\$S 0.5 M.
- **Availability facts:**
 - The target availability in most telecom sites and many modern datacenters is of 5-nines.
- **Origin of efficiency and availability issues:**
 - Electric architecture (the focus of this presentation)
 - Air flow and thermodynamics (only considered here through the effects on electric supply).

Traditional architecture: Availability

- A/C electric supply availability calculation:

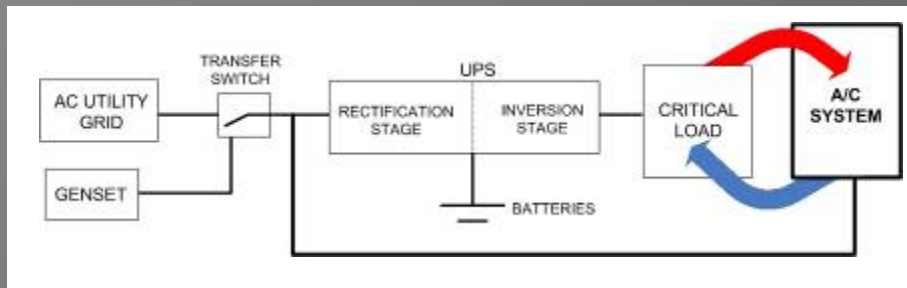
$$A_{ac} = \left(1 - \frac{(\lambda_{GS} + \rho_{GS} \mu_{MP}) \lambda_{MP}}{\mu_{MP} (\mu_{MP} + \mu_{GS})} \right) A_{TS}$$

- Telecom or IT equipment cooling availability:

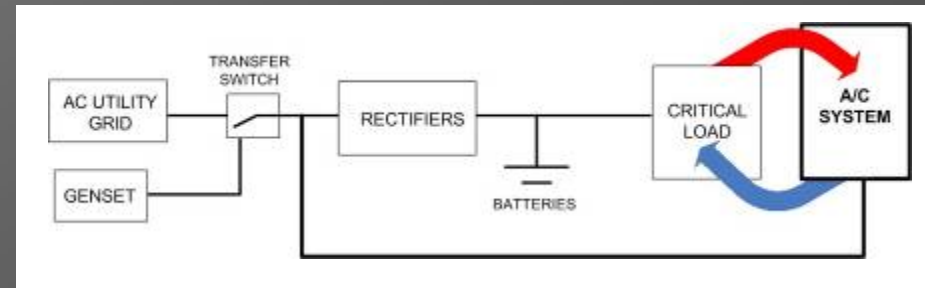
$$A_{A/C, SYS} = A_{ac} a_{A/C}$$

- Hence, at most the cooling availability equals the ac electric supply availability.

- Architectures:



Datacenter



Telecom central office

Traditional architecture: Availability

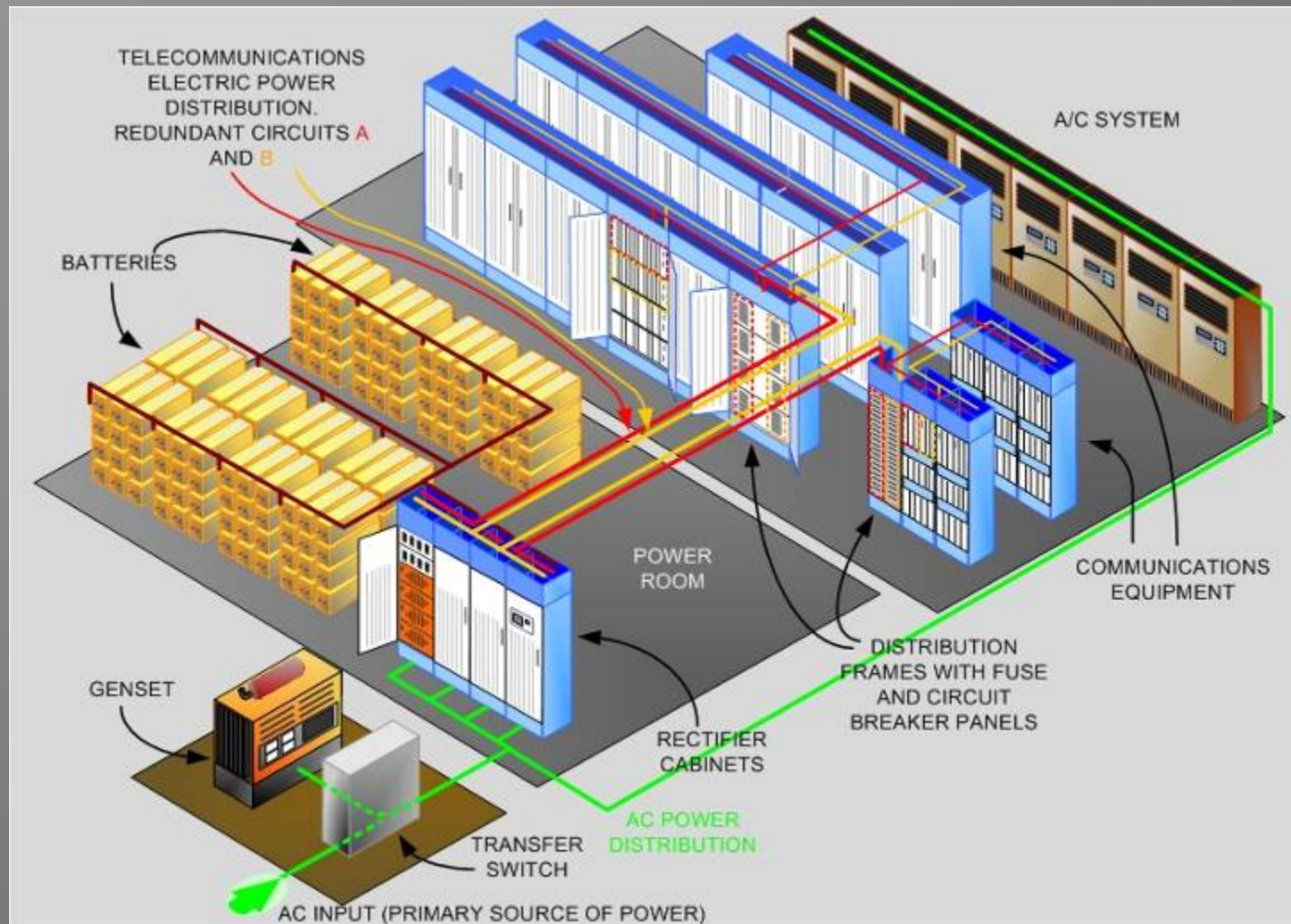
- Typical electric feed availabilities:

Item	MUT* (hours)	MDT** (hours)	Availability
Genset (Average from [13]-[17]) ($\rho_{GS}=0.0241$)	823	5	0.9939
ac mains [13]	2440	2.08	0.999150

- Hence, A_{ac} is 4-nines and $A_{A/C,sys}$ equals 4-nines or less. This is at least one order of magnitude less than what it is required.
- Worst failure mode: utility grid outage followed by a genset failure.
 - Thermal inertia prevents immediate IT or telecom equipment failure.
 - But statistically, the ac mains will take 2 hours to be repaired and the genset 5 hours.
 - Inhomogeneous heat generation distribution may lead to some critical load failures within this timeframe.
 - Datacenter heat density increase aggravates the problem.
 - Even if failure does not occur, higher temperatures decrease components life.

Traditional architecture: Availability

- Additional availability issue: Lack of redundant power supply paths.

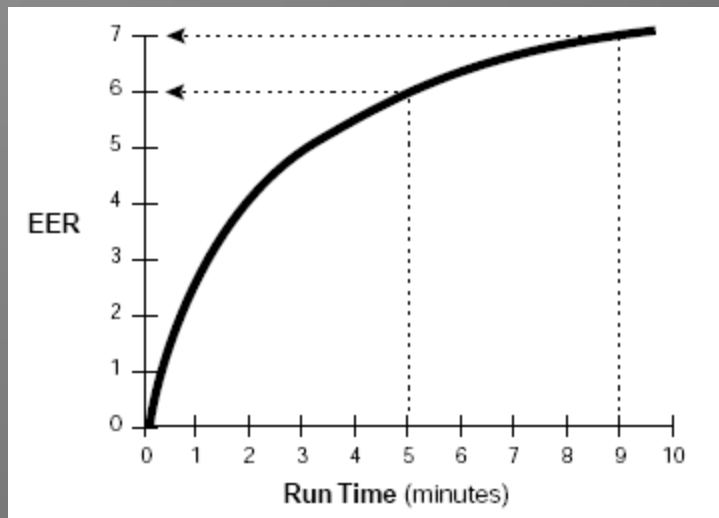
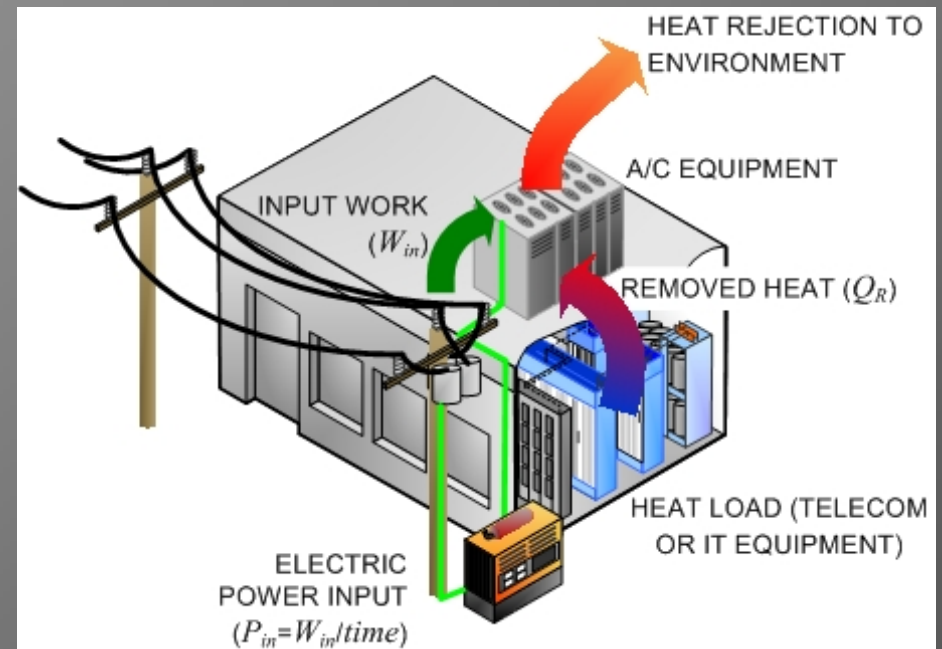


Traditional architecture: Efficiency

- Energy efficiency evaluation :
 - Energy Efficiency Ratio (EER):

$$(EER) = \frac{Q_R [\text{BTU/hr}]}{\frac{W_{in} [\text{Watts}]}{\text{sec}}}$$

- Coefficient of performance (COP):
(COP) = 0.293(EER)

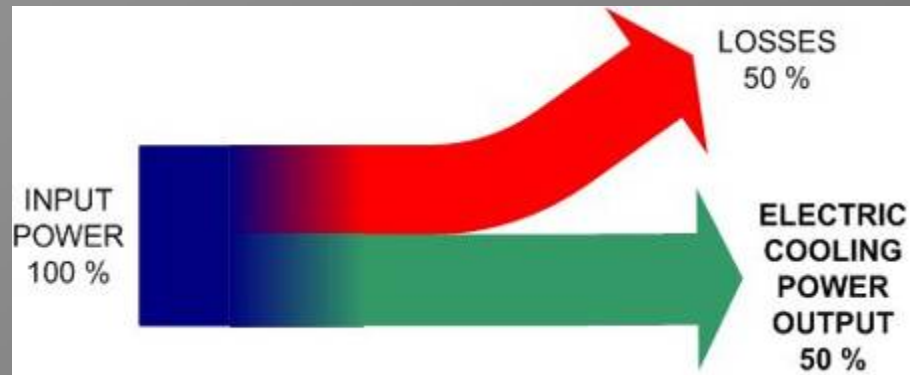


EPA 430-F-97-028

- Discontinuous operation reduces the efficiency up to a half

Traditional architecture: Efficiency

- For a typical A/C with an EER of 10, rated efficiency when operated continuously is 75 %. Actual electric efficiency is 50 %.



- If a standard ac-fed variable speed drive (VSD) is used to drive the A/C system continuously, the efficiency can reach 72 %.



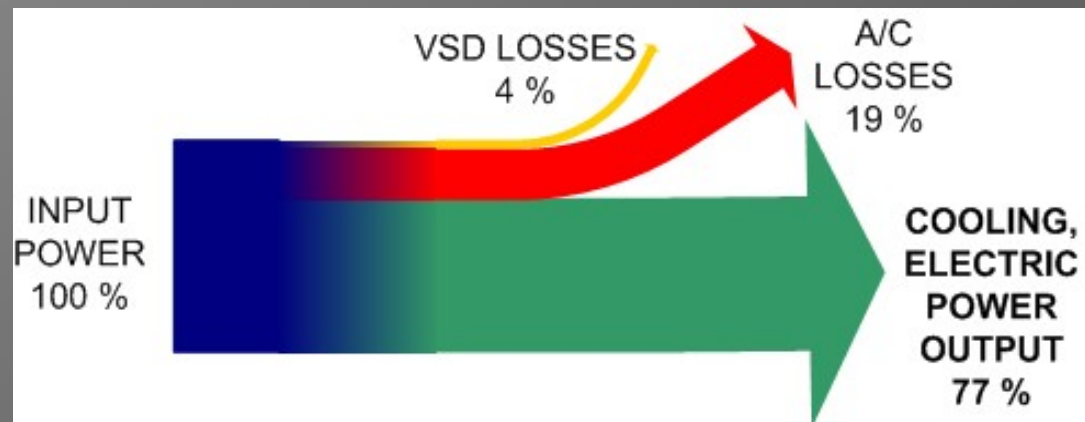
Optional Architectures: ac vs. dc

Availability:

- dc is several times more reliable than ac (NTT data from 30,000 systems [28])

Efficiency:

- Efficiency gains in energy conversion interfaces makes dc systems 5 % to 7 % more efficient than ac systems.
- dc powered VSDs are 5 % more efficient than equivalent ac powered VSDs because the rectification stage is avoided.



Optional Architectures: ac vs. dc

Additional advantages of dc architectures over equivalent ac architectures:

- dc converters are easier to control and to parallel
- dc architectures facilitates implementing modular designs.
- Thus, dc power distribution seems to be more suitable for rack-mounted and rack-integrated distributed A/C systems.
- Modular design makes A/C systems more flexible and easier to expand, allowing for a more effective capital investment management and for a better planning of the entire facility power installation.
- Dc power distribution systems are also a more natural option for telecommunications and IT load integration because most of these loads are dc loads. Although A/C as loads are mostly motors, the use of VSD makes A/C systems a primarily dc load as well.
- dc systems components tend to be more compact than equivalent ac ones. This is true for A/C systems since the use of VSD opens the possibility of utilizing fans and pump motors designed for higher frequencies than those used in utility grids, making the systems lighter and smaller

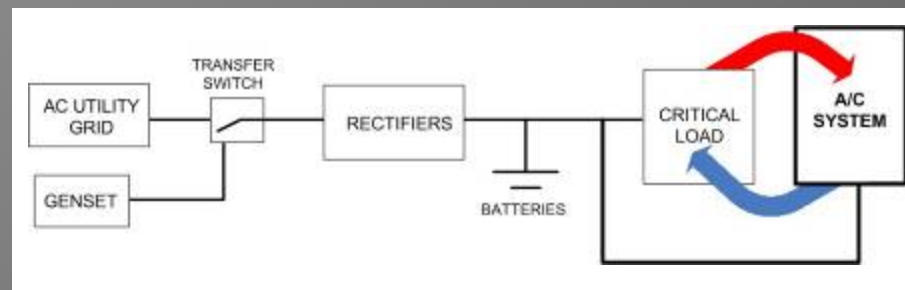
Options based on the Traditional Architecture

Impractical solution because:

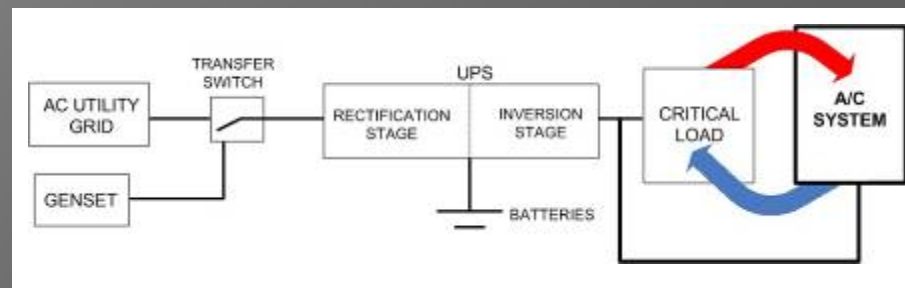
- Battery capacity needs to be significantly increased to add the A/C system power consumption.
- Very expensive solution.

Additional issues

- Rectification losses still present



dc telecom central office



ac datacenter

Options based on Distributed Generation

Fundamental concepts:

- Local power generating units are the primary system power source.
- The ac utility grid is an auxiliary source of power.
- Traditional architectures are energy-based systems whereas microgrid-based systems are power-based systems.
- Microgrid-based systems require much less energy storage.
- Well designed microgrids can exceed 5-nines availability.
- There are two alternatives to operate A/C systems in microgrid-based power plants:
 - Pure electrically driven A/C system.
 - Thermodynamic driven A/C system: Combined Heat and Power (CHP)

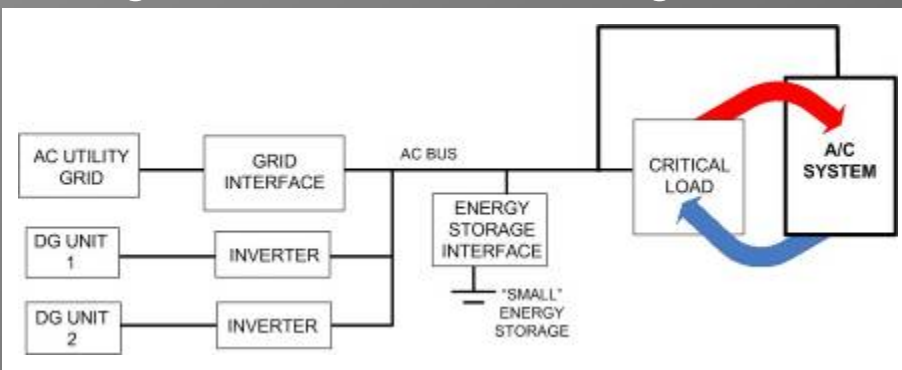
DG-based A/C System – Without CHP

Advantages over previously discussed options:

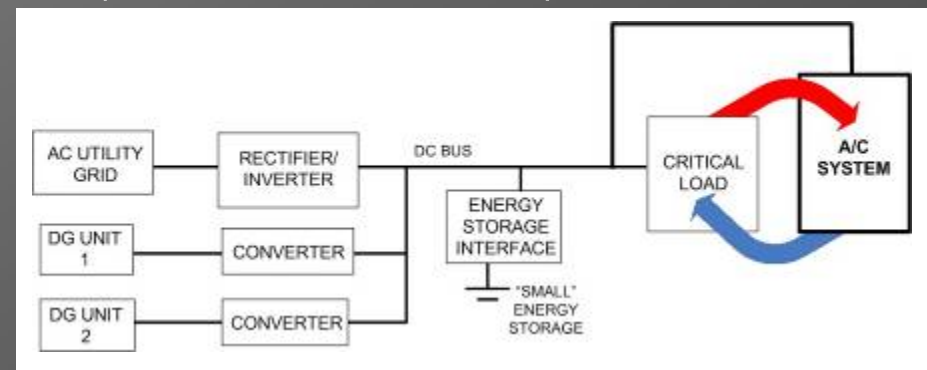
- Better availability thanks to diverse power input.
- Fully independent control from the grid.
- Better efficiency. Thanks to the independent control the entire system (the power electronic interfaces, the air conditioning, and the DG units) can be operated at its maximum efficiency point. E.g., one of the strategies is to operate the air conditioning continuously.
- Few stored energy is needed. Continuous operation of air conditioning contributes to reduced energy storage needs

Potential issues:

- High cost of DG units might be an issue (but it can be offset)



ac microgrid



dc microgrid

DG-based A/C System – With CHP

Characteristics:

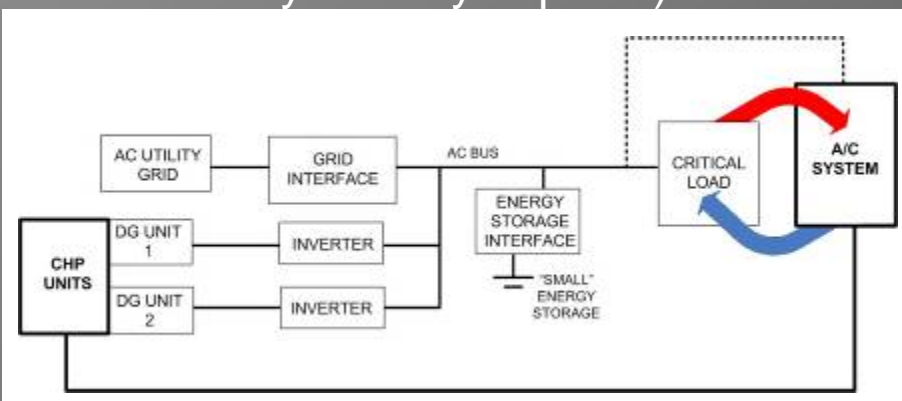
- Uses absorption chillers that require very little electricity – the compressor is driven by waste heat generated by some DG technologies (some type of fuel cells, microturbines, and others)

Advantages:

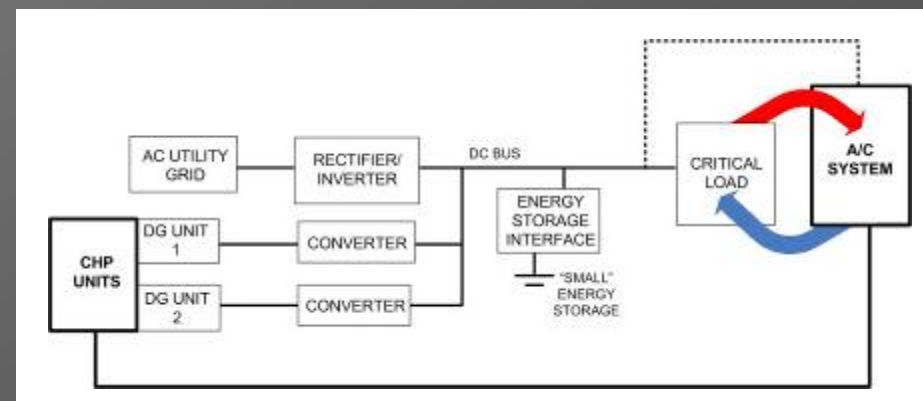
- No extra DG capacity needed for the A/C system.
- Good overall efficiency thanks to use of waste heat.

Potential issues:

- Some DG technologies may not generate enough heat – CHP COP can be as low as 50 %
- Availability might be negatively affected without a good design (water for the chillers and modularity are key aspects)



ac microgrid



dc microgrid

Conclusions

- The traditional approach for A/C systems seems inadequate for telecom and IT applications because the energy efficiency is poor and the availability target is not met.
- VSD is essential to improve energy efficiency.
- dc power architectures seem to have better availability and energy efficiency than the equivalent ac power designs.
- An impractical option is to feed the A/C system from the load's power bus.
- Using DG leads to two better solutions: with and without CHP
 - Both options seems to improve efficiency and availability.
 - CHP-based A/C systems seems to be more efficient than without CHP
 - Water for absorption chillers in CHP options might be an issue in critical situations (e.g., after a natural disaster).
 - Designs without CHP could be designed to be more flexible and modular than equivalent designs with CHP.

Last minute additions

- Natural disasters may highlight shortcomings of the existing traditional architecture.
- Potential issues with electric and A/C architectures at a central office recently affected by a Hurricane:

