Alternative Power Generation Technologies for Data Centers and Network Rooms

White Paper #64

Legendary Reliability™

Revision 1

Executive Summary

Fuel Cells and Micro Turbines are new technology alternatives for power generation for data centers and network rooms. This paper discusses the various modes of operation of these systems and examines benefits and drawbacks of the technologies when contrasted with conventional alternatives such as standby generators.

Introduction

Power generation is a key component of a high availability power system for data centers and network rooms. Information Technology systems may operate for minutes or even a few hours on battery or flywheel power, but local power generation capability is required to achieve “five-nines” availability. In locations with poor power, power generation may be needed to achieve 99.99% or even 99.9% availability[1].

Standby diesel or gas-fired generators are the conventional solution to this problem, when combined with a UPS. In high availability installations, an N+1 array of such standby generators is used.

Fuel cells and Micro Turbines have been suggested as an appropriate alternative for power generation for network rooms and data centers. Such systems can be utilized continuously to power the network room or data center, they can be used to generate excess electric power which can be used for other loads or to backfeed the utility grid, or they can be used as standby generation. The system availability and the Total Cost of Ownership are greatly affected by how the systems are used, as described in the following sections.

Standby Mode

In this mode, the AC utility is the primary source of power, and local power generation is used only as a backup during a scheduled shutdown or failure of the AC mains. A UPS is used to bridge the time delay while the standby system starts. This is the mode of operation used in over 99% of network rooms and data centers that have local power generators.

Continuous Mode

In this mode, local power generation is the primary source of power, and utility mains power is used only as a backup during a shutdown or failure of the local power generation. The loads may operate from the local generator, or a UPS is used to bridge time delays during system switchover. The local generator supplies only the critical load; if the local power generator is oversized when compared with the load, then the power generation system may be underutilized, or operate at an undesirable point on its efficiency curve.

Utility-Interactive Mode

In this mode, local power generation is the primary source of power, and utility mains power is used only as a backup during a shutdown or failure of the local power generation. The local generator operates in parallel with the utility, such that any power generated in excess of the critical load power feeds the utility. In this mode the excess power may simply offset other non-critical loads at the facility, or it may even

[1] For quantitative data on how generation affects availability, see APC White Paper #24: “Effect of UPS on System Availability”

reverse the power flow into the utility. Typically, a UPS is required to buffer the critical load from the raw utility power. The power generation system is normally operated at the most cost effective point on its efficiency curve.

Fault Tolerance Configurations

Using any technology or mode, availability can be enhanced using the following techniques:

Dual Path Architecture

In this case, the entire power generation system would be duplicated. Ideally, this duplication would occur throughout the entire power system, all the way to the critical load, which itself would be configured to accept dual power inputs.

N+1 Architecture

In this case, the least reliable components in the power generation system would be comprised of multiple parallel units, such that if one fails the other(s) would be able to sustain the critical load

Determining Total Cost of Ownership

The economics may not always be the dominant driver in selecting a power generation system, but are always a very important consideration. The Total Cost of Ownership (TCO) of a power generation system consists of the following elements:

- Engineering costs
- Capital cost
- Installation/startup costs
- Maintenance costs
- Fuel costs
- Saved energy (offsetting fuel costs)

There are a number of situational factors that can dramatically alter the TCO calculation, including:

- Fuel vs. electricity cost
- Utility stranding or backup power charges
- Backfeed rates and regulations
- Percent load on the power system

A model can be constructed to estimate TCO for various technologies and operating modes. For conventional standby generators the data is readily available and reliable estimates are possible. For fuel cells and micro-turbines, forward-looking estimates of the equipment costs based on industry projections 3-5 years out can provide useful guidance regarding the future economics of these technologies.

Given the cost data for equipment, installation, maintenance, and energy, the TCO calculations for a typical 10 year data center lifetime are straightforward and will not be detailed here. A representative table of cost data and the resulting lifetime TCO calculations are described in Appendix 1.

Using the realistic forward-looking data in Appendix 1, the lifetime TCO for a power generation system for a 250kW data center is shown in Figure 1.

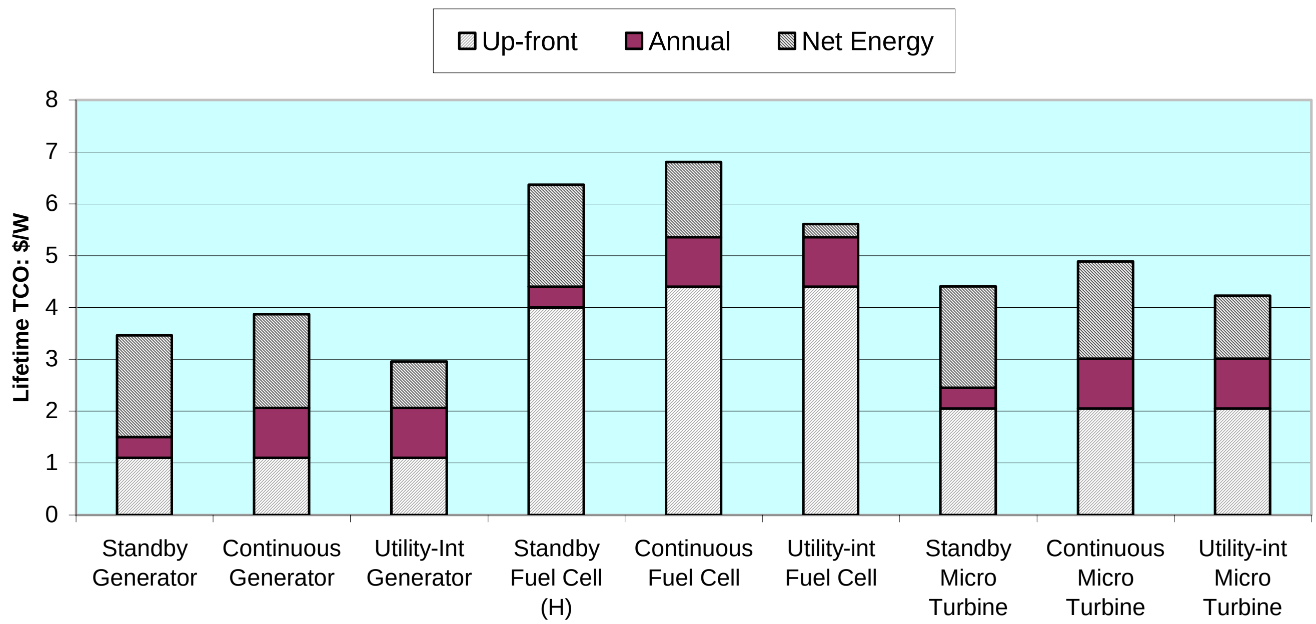

***Figure 1** -- Power generation system TCO for various technologies and modes operation*

An analysis reveals the following underlying patterns:

- Up-front cost is comparable to the lifetime energy cost
- The energy cost savings of fuel cells and micro-turbines are insufficient to offset the increased up-front costs of these technologies
- Given that the typical utilization fraction of the data center is significantly lower than 100%[2], continuous local power generation is the least cost effective choice when compared with either standby or Utility-Interactive modes.
- The inefficiency of local power generation nullifies most of the benefit of using lower cost fuel.

[2]For a discussion of typical utilization fraction, see APC White Paper #37: “Avoiding Costs of Oversizing Data Center and Network Room Infrastructure”

Other considerations

The economics suggest that fuel cells and micro-turbines are not attractive for data center power generation when compared with standby generators. However, there are a variety of situations or considerations that have been suggested as potential drivers for the adoption of fuel cell or micro-turbine technologies. These are discussed below

Emissions

Exhaust emissions may be limited by local regulation, or by company mandate. The local power generation system that creates the largest emission problem is the diesel engine. The licensing of diesel engines is complex, very site specific, and in some cases impractical or impossible. The logical argument in favor of the standby use of a diesel is that although the emissions are high, the operating time is low so that the cumulative emissions are low. However, in practice standby diesel systems generate prodigious quantities of visible smoke on start-up, particularly when rapidly subjected to load as they are in the standby power application. One result of this is that diesel startups are often subject to complaints from neighbors, which can result in the highly undesirable situation that they may be regulated "after the fact" by the actions of local authorities.

For purposes of the TCO analysis, natural gas or propane powered standby generators were assumed instead of the more popular diesels. These generators cost as much as 30% more than diesel generators but greatly reduce the emissions problem, particularly visible emissions. If a key goal is to reduce emissions, the data suggests that natural gas or propane powered generator sets are much more cost effective than fuel cells or micro-turbines.

Availability

The cost of downtime is very high for many data centers and network rooms. The suggestion has been made that fuel cells and micro-turbines could improve overall system availability when compared with standby generators. One statistic that is frequently cited is that a standby generator will only start 90% of the time when called upon.

To accurately assess this postulate, data on the reliability of fuel cells and micro turbines, along with the nature of the failure modes and their time-to-repair would be needed. This data is not yet available.

What is known is that fault tolerance investments can be made to increase availability of any power system, such as N+1 Architecture, and Dual Path Architecture as discussed earlier. In addition, design enhancements for concurrent maintenance, improved status monitoring, and improved maintenance are known to enhance availability. The evidence at this time suggests that the TCO savings of using a standby generator system could be applied to increasing the availability of such a system in order to offset any potential (and yet-to-be demonstrated) availability advantages of fuel cells or micro-turbines.

Elimination of other equipment

Many discussions of fuel cells and micro-turbines suggest that this technology could eliminate other devices in the power system, potentially reducing cost, increasing availability, and increasing efficiency. Elimination of the UPS or batteries is commonly discussed.

In the case of Utility Interactive mode operation, a UPS is still required to isolate the critical load from the raw utility. In the case of continuous mode operation, a UPS is still required to buffer the critical load from the effect of other facility loads like air conditioners. In the case of standby mode operation, the UPS is obviously required to carry the critical load until the generator can start.

The backup time of the UPS when used in continuous mode or in Utility-Interactive mode could, in principle, be lower than the UPS backup time of a system operated in standby mode. Consequently, the battery could be smaller. However, reducing battery run time for a given load increases the stress on the battery and decreases system reliability. Reducing the battery size to bring the run time under 5 minutes is not practical using current battery technology. The use of UPS with flywheels in conjunction with a Continuous Mode or Line-Interactive mode power generation system could eliminate batteries. However, the data does not indicate that this offers any TCO advantage. Furthermore, real world data center failure data suggests that the backup time provided by batteries can provide time for human intervention during abnormal fault conditions that can prevent downtime.

Conversion from AC to DC

Some discussions of fuel cells and micro-turbines suggest that this technology could eliminate the use of AC power in the data center and network room. The concept is that DC would be provided to the critical loads and there would be less stages of power conversion. Both fuel cells and micro-turbines generate DC, which could potentially be used directly.

This vision is not realistic or practical. First, many devices that are needed to operate a data center or network room require AC and it is very unlikely these devices will be available in DC versions. These include lighting, Air Conditioning, office equipment, and even personal computers. Furthermore, the assumption that DC distribution has efficiency or other advantages over AC is false[3]

Combined heat and power

All power generation systems generate more heat than electrical power. If the heat can be harnessed for useful work, displacing the need for other heat energy, then significant savings are possible. Unfortunately, data centers and network rooms are substantial heat generators, and do not require supplemental heat. Therefore an alternate use for continuous heat power is required before a substantial savings could be obtained. Few sites meet this criteria; however for those particular sites the data suggests that the TCO for

[3] For a discussion on the use of DC in the data center, consult APC White Paper #63: “AC vs. DC for Data Centers and Network Rooms”

a Utility Interactive data center power generation system could be lower than the TCO of a standby power system.

Note that when combined heat and power are used, the data suggests that the natural gas powered engine will still have a significant TCO advantage over fuel cells or micro-turbines.

Combined cooling and power

Another application for the waste heat generated during power generation is to use it to drive cooling equipment using a device called an absorption chiller. In this case the waste heat is actually converted to cooling capacity, which is needed by the data center. Since a typical data center may draw as much electrical power to run the cooling system as it does to run the critical load, this has a double benefit of reducing the electrical load AND improving the efficiency of the power generation system. Theoretically, this could significantly reduce TCO for a data center.

Providing fault tolerance options for combined cooling and power systems without losing the benefits remains a technical challenge at this time.

The performance of combined cooling and power using an absorption chiller improves with higher temperature waste heat. For this reason fuel cell technologies such as PEM are unsuited for use with absorption chillers due to low operating temperature. Micro-turbines have the waste heat characteristics best suited for combined cooling and power applications.

Complete utility independence

It is occasionally suggested in the literature that fuel cells or micro-turbines could allow a data center to completely disconnect from the Utility system. This would eliminate standby charges or other utility fees. This could allow a data center to be sited in a location where it is not possible to obtain incremental AC utility power.

Utility independence does give rise to a whole new group of technical problems, including the cold-start of the power generation plant, the loss of the utility as a backup power source. In addition, the facility is still dependent on fuel delivery by pipe or truck, and therefore subject to labor strikes or other supply disruptions. The gas utility may terminate supply in a crisis, such as when gas pressure falls during high demand periods like unusually cold weather.

The data suggests that if complete utility disconnection were an objective, then conventional engine powered generator sets still have a TCO advantage over fuel cells or micro turbines.

Conclusion

Local power generation for extended outages remains a requirement for achieving high availability for data centers and network rooms. The conventional approach of using standby engine-driven power generation has an economic advantage over fuel cells and micro-turbines for the foreseeable future.

If pressure to reduce emissions is a concern, then a move away from diesels to natural gas or propane powered engine generators is the most likely outcome, rather than adoption of fuel cell or micro-turbine technology.

Technological innovations that dramatically reduce the cost of fuel cells and reformer technology could allow fuel cells to displace engine generator sets, but methods to achieve such cost reductions are not yet demonstrated.

A combination of Utility-Interactive mode with combined cooling and power has the potential to allow micro-turbines to have a significant TCO advantage over conventional approaches. However, there are a number of technical hurdles to overcome, including cost-effective methods for providing fault tolerance.

To maximize the availability of the power system, improvements in the fault tolerance architecture of the current engine-based technology are the best investment from a user standpoint. Such investments include dual power path architecture, N+1 architecture, improved system integration and testing, and improved instrumentation and monitoring.

Appendix 1: TCO Data

This appendix includes the data that was used to generate Figure 1 in the paper and briefly explains the model. The model takes up-front and recurring costs including energy costs, accrues them over the system lifetime, and then expresses them in dollars per watt of system rating.

The following assumptions apply:

The standby fuel cell was assumed to be hydrogen based, while the continuous fuel cells were assumed to have a reformer system and operate on natural gas.

The generator system was assumed to be natural gas or propane and not a diesel. Diesel equipment costs would be lower by approximately 25%.

A standby charge from the utility company was assumed for all systems that are not operated in standby mode. This is the annual fee, which the utility company charges in order to provide electrical service that could be used as a backup. This is expressed as fraction of the base rate applied to the system rating.

The electrical rate is the average rate for continuous operation and includes charges related to use at peak times. This cost will typically be a higher number than the base rate.

The model was developed using costs for systems in the range of 250kW. Note that the $/W costs will be lower for systems of substantially higher power, and may be higher for systems of substantially lower power.

Table 1 *-- Data used for TCO calculations*

Design Inputs

system lifetime	years	10
percent load	%	35%
rated capacity	kW	250

Cost Inputs

		Standby Generator	Continuous Generator	Utility-Int Generator	Standby Fuel Cell (H)	Continuous Fuel Cell	Utility-int Fuel Cell	Standby Micro Turbine	Continuous Micro Turbine	Utility-int Micro Turbine
Capital/up-front costs										
System Engineering	$/W	0.2	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.4
Generator Unit (3 yrs)	$/W	0.4	0.4	0.4	2	2	2	0.8	0.8	0.8
DC/AC inverter	$/W	0	0	0	0.3	0.3	0.3	0.3	0.3	0.3
Ancillary equip	$/W	0.3	0.3	0.3	0.4	1.4	1.4	0.3	0.3	0.3
Fuel Storage	$/W	0.1	0.1	0.1	0.7	0.1	0.1	0.1	0.1	0.1
Gen install	$/W	0.1	0.1	0.1	0.2	0.2	0.2	0.15	0.15	0.15
Maintenance costs										
Maint cost	$/W/Y	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Rates and Charges										
Stranding charge	$/kW	0	0	0	0	0	0	0	0	0
Utility standby charge	% of rate	0%	10%	10%	0%	10%	10%	0%	10%	10%
Electric rate	$/kw-hr	$0.070	$0.070	$0.070	$0.070	$0.070	$0.070	$0.070	$0.070	$0.070
fuel rate	$/kw-hr	$0.017	$0.017	$0.017	$0.200	$0.017	$0.017	$0.017	$0.017	$0.017
byback rate	$/kw-hr	$0.070	$0.070	$0.070	$0.070	$0.070	$0.070	$0.070	$0.070	$0.070

Performance

		Standby Generator	Continuous Generator	Utility-Int Generator	Standby Fuel Cell (H)	Continuous Fuel Cell	Utility-int Fuel Cell	Standby Micro Turbine	Continuous Micro Turbine	Utility-int Micro Turbine
generation no-load loss	%	25%	25%	25%	10%	10%	10%	20%	20%	20%
generation full load efficiency	%	30%	30%	30%	40%	35%	35%	28%	28%	28%
% time on utility	%	100.0%	0.1%	0.1%	99.9%	0.1%	0.1%	99.9%	0.1%	0.1%

Lifetime TCO

		Standby Generator	Continuous Generator	Utility-Int Generator	Standby Fuel Cell (H)	Continuous Fuel Cell	Utility-int Fuel Cell	Standby Micro Turbine	Continuous Micro Turbine	Utility-int Micro Turbine
Up-front	$/W	$1.10	$1.10	$1.10	$4.00	$4.40	$4.40	$2.05	$2.05	$2.05
Annual	$/W	$0.40	$0.96	$0.96	$0.40	$0.96	$0.96	$0.40	$0.96	$0.96
Net Energy	$/W	$1.96	$1.81	$0.90	$1.97	$1.45	$0.25	$1.96	$1.88	$1.22
Total $$	K$	$865	$967	$739	$1,593	$1,702	$1,402	$1,102	$1,222	$1,057

Intermediate Computations

load energy	kw-hr	7,000,000								
One-time cost	K$	$275	$275	$275	$1,000	$1,100	$1,100	$513	$513	$513
Standby charge	K$/lifetime	$0	$140	$140	$0	$140	$140	$0	$140	$140
Other Yearly costs	K$/lifetime	$100	$100	$100	$100	$100	$100	$100	$100	$100
Summed yearly costs	K$	$100	$240	$240	$100	$240	$240	$100	$240	$240
Generator fixed energy loss	kw-hr	0	4,995,000	4,995,000	2,000	1,998,000	1,998,000	4,000	3,996,000	3,996,000
Generator proportional loss	kw-hr	0	14,568,750	41,625,000	9,800	12,287,700	35,107,714	16,600	16,583,400	47,381,143
Generator energy out	kw-hr	0	6,993,000	19,980,000	7,000	6,993,000	19,980,000	7,000	6,993,000	19,980,000
Utility Energy reqd	kw-hr	7,000,000	7,000	7,000	6,993,000	7,000	7,000	6,993,000	7,000	7,000
Fuel Energy reqd	kw-hr	0	26,556,750	66,600,000	18,800	21,278,700	57,085,714	27,600	27,572,400	71,357,143
Utiltiy Energy Sold	kw-hr			12,980,000			12,980,000			12,980,000
Energy cost	K$/lifetime	$490	$452	$1,133	$493	$362	$971	$490	$469	$1,214
Utility Energy Sold	K$/lifetime			$909			$909			$909
Net Energy Cost	K$/lifetime	$490	$452	$224	$493	$362	$62	$490	$469	$305