LEVERAGING DISTRIBUTED GENERATION USING CHP IN DATA CENTERS

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ABSTRACT

Data center owners and operators constantly balance redundancy, power resilience, and flexibility for future expansions with operational efficiency requirements and concerns to maintain facility uptime. Add to these constraints the growing anxieties about security, energy prices, economic competitiveness, and climate change; and distributed generation using combined heat and power (CHP) begins to offer significant benefits in data centers for efficiently meeting these growing demands in.

Data centers, with their constant cooling load, can realize large cost savings from CHP, especially in markets with higher utility costs than the national average. CHP solutions lower total energy use (lower power usage effectiveness, or PUE) and reduce emissions by recovering the waste heat for useful purposes, significantly improving overall energy efficiency compared to traditional utility-sourced power. Cost savings come from two main areas that traditionally represent large operation costs – mechanical cooling and demand charges. Waste heat from on-site generation reduces electrically driven chiller loads, and the CHP-generated electricity helps offset site peak demand and consumption charges. By relying on grid power less, on-site generation also benefits data centers with added redundancy, improved resiliency and long-term ride-through capability in the event of a loss of utility power.

This paper reviews existing literature of CHP research and discusses the benefits of CHP for data centers as well as its potential within a microgrid system. Traditional power sources and net energy are compared to a CHP installation, providing a quantitative analysis of savings through deploying CHP in data centers.

INTRODUCTION TO CHP

CHP, also known as cogeneration, is an efficient, clean approach to concurrently produce electricity and useful thermal energy (for cooling data center equipment) with a single fuel source, typically from natural gas. Unlike central station generation, CHP is a type of distributed generation located at or near the point of consumption. According to a 2012 report published by the Department of Energy, the average power generation efficiency in the United States has remained at 34 percent since the 1960s, with the balance of the energy used for power generation lost as waste heat exhausted to the atmosphere. CHP captures this waste energy, a by-product of power generation, and uses it to cool data center equipment. CHP systems commonly achieve total system efficiencies in the range of 60 to 80 percent. See Figure 1 for an overview of CHP benefits.

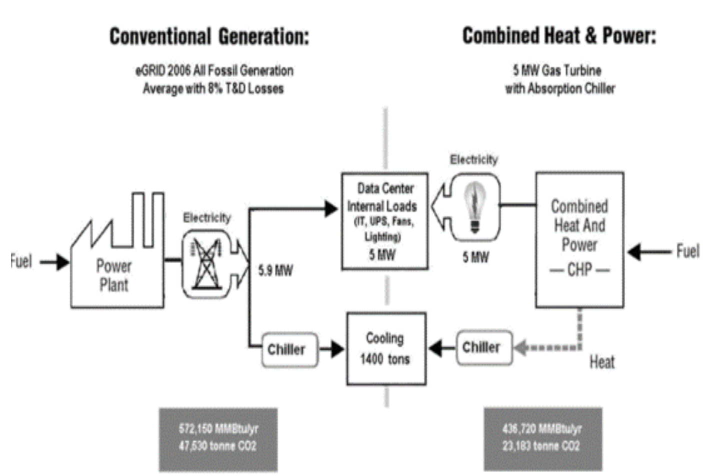


FIGURE 1: OVERVIEW OF CHP BENEFITS [1]

CHP is not a single technology but a suite of technologies that can use a variety of fuels to generate electricity at the point of use, and recovers the heat normally lost in the power generation to provide needed heating and/or cooling [2]. This improves overall fuel efficiency, lowering costs and CO_2 emissions. The most common type of CHP system for data centers uses the "topping" cycle. In a topping-cycle system, fuel is first combusted to generate electricity. A portion of the heat energy left over from the electricity generation process is then converted into useful thermal energy - hot water or steam for use with an absorption chiller. Data centers use the electricity produced onsite by the CHP to offset electricity procured from the grid and the thermal energy recovered from CHP to produce chilled water to offset chilled water produced with traditional electric chillers.

Examples of the two most common topping-cycle CHP configurations for data centers are [3]:

- A reciprocating engine or gas turbine burns fuel to generate electricity and a heat recovery unit captures heat from the exhaust and cooling system. The recovered waste heat is converted into useful thermal energy, usually in the form of steam or hot water for use by an absorption chiller (see figure 2).
- A steam turbine uses high-pressure steam from a fired boiler to drive a generator producing electricity. Low-pressure steam extracted exiting the steam turbine then drives an absorption chiller to produce chilled water.

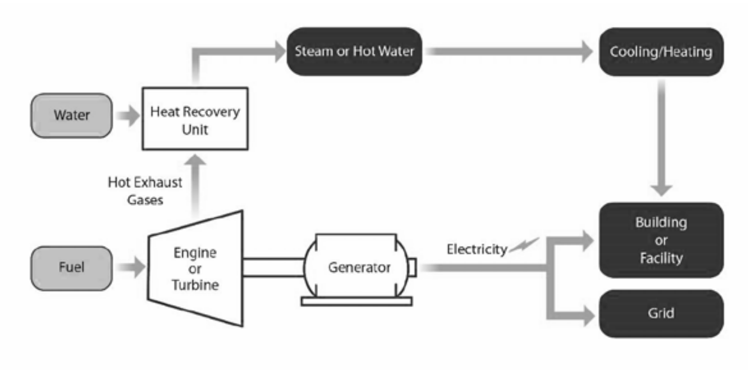


FIGURE 2: TYPICAL RECIPROCATING ENGINE/GAS TURBINE CHP CONFIGURATION (TOPPING CYCLE) [2]

Another type of CHP system, known as a "bottoming" cycle, is rarely used in data centers. In a bottoming-cycle CHP system, fuel is first combusted to provide thermal energy input to industrial process equipment and the heat rejected from the process is then captured for power production.

HISTORY OF CHP DEVELOPMENT IN THE US [3]

Decentralized CHP systems located at industrial sites and urban centers were the foundation of the early electric power industry in the United States. In fact, the nation's first commercial power plant, Thomas Edison's Pearl Street Station, began operations in New York City in 1882, and served lower Manhattan with electricity for lighting and steam for local manufacturing. However, as power generation technologies advanced, the power industry began to build larger central station facilities to take advantage of increasing economies of scale. CHP became a limited practice among a handful of industries (paper, chemicals, refining, and steel) that had high and relatively constant steam and electric demands and access to low-cost fuels.

By the 1960s, the US electricity market was dominated by mature, regulated electric utilities using large, power-only central station generating plants. Because of this competitive position, utilities had little incentive to encourage customer-sited generation, including CHP. Regulatory barriers at the state and federal levels further discouraged broad CHP development.

Public Utilities Regulatory Policies Act

Partly in response to the oil crisis of the early 1970s, Congress in 1978 passed the Public Utilities Regulatory Policies Act (PURPA) to promote energy efficiency. PURPA encouraged energy-efficient CHP and power production from renewables by requiring electric utilities to interconnect with qualified facilities (QFs). CHP facilities had to meet minimum fuel-specific efficiency standards to become a QF. PURPA required utilities to provide QFs with reasonable standby and backup charges, and to purchase excess electricity from them at the utilities' avoided costs. PURPA also exempted QFs from regulatory oversight under the Public Utilities Holding Company Act and from constraints on natural gas use imposed by the Fuel Use Act. Shortly after enacting PURPA, Congress passed a series of tax incentives for energy efficiency technologies, including CHP. The incentives included tax credits and shortened the depreciation schedule for CHP systems. PURPA and the tax incentives successfully expanded CHP in the United States.

Post-PURPA

While PURPA promoted CHP development, it also had unforeseen consequences. PURPA was enacted at the same time that larger, more efficient, lower cost combustion turbines and combined cycle systems became widely available. These technologies produced more power in proportion to useful thermal output compared to traditional boiler/steam turbine CHP systems. Therefore, the power purchase provisions of PURPA, combined with the availability of these new technologies, resulted in the development of very large merchant plants designed for high electricity production. For the first time since the inception of the power industry, non-utility participants were allowed into the power market, triggering the emergence of third-party CHP developers with more interest in electric markets than in thermal markets.

BENEFITS OF CHP IN DATA CENTERS

CHP offers the opportunity to improve resiliency and energy efficiency, reduce emissions, and increase reliability by keeping critical facilities running without any interruption of electric or thermal service. When the electricity grid fails, specially configured CHP systems can continue to operate, ensuring an uninterrupted supply of power and cooling to critical facilities like data centers.

The most common benefits of CHP include [2, 4]:

Data Centers

- Reduced Energy Costs: CHP utilizing thermal recovery to produce chilled water using absorption chillers requires less fuel than traditional electric chillers running on grid-supplied electricity. With CHP, the electricity is generated at the point of use and the transmission displacing distribution losses that occur when electricity travels over power lines from central power plants. Because of the energy efficiency benefits, CHP can save facilities money for energy and also hedge against fluctuations in electricity costs.
- Improved Electric Reliability: Data centers configured for synchronous operation and parallel connection with the utility grid are less susceptible to grid failures. CHP helps maintain business continuity.
- Improved Power Quality: CHP reduces line losses and voltage sags, thereby improving power quality at the data center.
- Improved Energy Security: With onsite power generation capabilities using CHP, the data center is less susceptible to damages that can occur from natural disasters and/or terrorist attacks.

- Flexibility for Future Growth: CHP provides data center owners with options to meet growing electrical power needs without sacrificing reliability.

Utility

- Alternative to utility distribution grid expansions / upgrades: Onsite power production using CHP reduces, or in some cases, defers the infrastructure (line and substation) upgrades.
- CHP reduces energy losses in transmission lines.
- CHP improves grid reliability.
- CHP has higher energy conversion efficiencies than central generation, since waste heat from CHP is utilized for cooling.
- CHP results in faster permitting than transmission line upgrades.

Society

- Improved environmental quality: CHP has higher fuel utilization efficiency, which reduces emissions per unit of useful output.
- CHP results in higher fuel utilization efficiency, which results in the conservation of energy resources. Fuel used for supporting various data center functions is also reduced. In addition, fresh water use for power generation is reduced with the use of CHP.
- No ratepayer investment is required in generating, transmitting or distributing power.

CHP SYSTEM COMPONENTS[5, 6]

CHP system components consist of the prime mover (heat engine), generator, electrical interconnection, and heat recovery.

Prime-mover Technologies [5]

Prime-mover technologies consist of:

1. Reciprocating internal combustion engines (spark ignition and compression) make up the majority of the CHP systems but account for a small percent of total capacity. Improvements over the last 30 years have increased the efficiency and lowered the emissions of these machines. Reciprocating engines offer a broad range of capacities at low cost with high reliability. Spark-ignited engines represent 84 percent of the installed reciprocating engine for CHP, with the remainder using compression ignition diesel-cycle engines. The exhaust heat characteristics of reciprocating engines make them ideal for producing hot water.

2. Gas turbines make up nearly two-thirds of CHP system capacity and can be made in a wide range of sizes, although the most economical are in sizes greater than 5 MW. The high-temperature heat from the turbine exhaust can produce high-pressure steam.

3. Microturbines are very small, stationary gas turbines. They burn clean and are compact and simple. with capacities ranging from 30 to 250 kW for single-turbine systems with multiple turbine packages available up to 1,000 kW.

4. Fuel cells use an electrochemical reaction that converts hydrogen into water and electricity. A variety of hydrocarbon sources can provide the hydrogen fuel: natural gas, coal gas, methanol, etc. Fuel cells are characterized by the type of electrochemical process utilized: phosphoric acid fuel cells (PAFC), commercially available in two sizes, 200 kW and 400 kW, proton exchange membrane fuel cells (PEMFC), molten carbonate fuel cells (MCFC) commercially available, 300 kW and 1200 kW, and solid oxide fuel cells (SOFC) and alkaline fuel cells (AFC). Although low-production volume results in high capital costs, fuel cells remain in demand because of their low air emissions, low noise, and generous market subsidies. Heat is recovered as hot water or low-pressure steam (<30 psig), with the quality of heat dependent on the type of fuel cell and operating temperature.

Table 1 shows a summary of CHP technology advantages and disadvantages.

Table 2 presents the CHP prime-mover performance characterizations.

TABLE 1: SUMMARY OF CHP TECHNOLOGY ADVANTAGES AND DISADVANTAGES [1]

CHP system	Advantages	Disadvantages	Available Sizes and Costs
Gas Turbine	• High reliability. • Low emissions. • High-grade heat available for double-effect absorption chiller • Well sized for new enterprise class data centers • Small federal incentive available (-10% of cost if overall efficiency is 60% or greater)	• Requires high-pressure natural gas or an in-house gas compressor. • Poor efficiency at low loading. • Output falls as ambient temperature rises. • May produce more cooling than the data center needs. • Requires additional operations and maintenance by experienced operations staff or outsource	500 kW to 40 MW $1,200-2,500/kW
Microturbine	• Small number of moving parts. • Compact size and light weight. • Low emissions. • Can be matched to direct fired exhaust driven double effect absorption chiller. • Power electronics could be modified for future DC power data center • Small federal incentive available (-10% of cost if overall efficiency is 60% or greater)	• High costs, few active vendors • Relatively low electrical efficiency. • Poor efficiency at low loading. • Output falls as ambient temperature rises. • Limited choice of direct exhaust fired chillers. • Limited choice of direct exhaust fired chillers.	30 kW to 1,000kW $2,000-3,000/kW
Reciprocating Engine: Spark Ignition (SI) & Compression	• High power efficiency with part-load operational flexibility. • Fast start-up. • Relatively low investment costs. • Can be used in island mode and have good load following capability. • Operate on low-pressure gas. • Small federal incentive available (-10%of cost if overall efficiency is 60% or greater)	• High maintenance costs. • Limited to lower temperature cogeneration applications. • Relatively high air emissions (difficulty permitting in some areas) • Must be cooled even if recovered heat is not used. • High levels of low-frequency noise. • Generally limited to single-effect absorption chiller, though larger engines could use exhaust heat for double-effect chillers.	High speed (1,200 RPM) <4MW $1,500-2,500/kW Low speed (60-275 RPM) <65MW $900-1,500 *I* kW

Fuel Cells	• Lowest emission profile of any other on-site power generation technology • Electrochemical fuel conversion, No combustion • No noise, allowing indoor installation • High efficiency over load range. • Modular design. • High temp technologies can use double effect absorption chillers • Tax credits and other incentives available • DC power generation could be used directly in data center of the future • Large federal incentive available ($3,000/kW or 30%of cost, whichever is less)	• High capital costs • Industry is less mature • Power density is lower with efficiency reductions over the product life. • Fuels requiring processing unless pure hydrogen is used. • Requirement for stack replacement produces a high maintenance cost allocation	200 kW to 1,200 kW $4,000-6,000/kW

TABLE 2: CHP PRIME-MOVER PERFORMANCE CHARACTERIZATIONS [5]

Technology	Recip. Engine	Gas Turbine	Microturbine	Fuel Cell
Electric efficiency (HHV)	27-41%	24-36%	22-28%	30-63%
Overall CHP Efficiency (HHV)	77-80%	66-71%	63-70%	55-80%
Part-load	OK	Poor	OK	Good
Availability	96-98%	93-96%	98-99%	>95%
Hours to overhauls	30,000-60,000	25,000-50,000	40,000-80,000	32,000-64,000
Start-up time	10 sec	10 min -1 hour	60 sec	3 hrs -2 days
Fuel pressure (psig)	1 to 75	100 to 500 (compressor)	50-140 (compressor)	0.5-45
Fuels	Natural gas, biogas, LPG, sour gas, industrial waste gas, manufactured gas	Natural gas, synthetic gas, landfill gas, and fuel oils	Natural gas, sour gas, liquid fuels	Hydrogen, natural gas, propane, methanol
Thermal output	Hot water, cooling, LP steam	Hot water, LP-HP steam	Hot water, chiller, heating	Hot water, LP-HP steam
NOx (lb/MMBTU) (not including SCR)	0.013 rich burn 3-way cat. 0.17 lean burn	0.036-0.05	0.015-0.036	0.0025-.0040
Total NOx (lb/MWh) (not including SCR)	0.06 rich burn 3-way cat. 0.8 lean burn	0.52-1.31	0.14-0.49	0.011-0.016

Generators [7, 5]
The second component in CHP systems is the generator.
Fuel cells produce electricity directly from an electrochemical process. Micro turbines are small combustion turbines approximately the size of a refrigerator. Both systems include an inverter; either to convert the direct current (DC) produced in the fuel cell to alternating current (AC) or to convert the frequency of the electricity produced by the micro turbine. Some data center designs have directly supplied the DC power produced by fuel cells to IT equipment, eliminating traditional server power supplies.

CHP systems configured with reciprocating engines and turbines use a either an induction or synchronous generator to convert mechanical shaft power into electricity.

Induction generators require an external excitation source and cannot operate without grid power. The output frequency of induction generators is regulated by the power system to which the induction generator is connected. Induction generators take reactive power from the power system for field excitation. If an induction generator supplies a standalone load, a capacitor bank must be connected to supply reactive power. Induction generators are simpler and less costly to interconnect to the grid.

In a synchronous generator, the voltage waveform is synchronized with (directly corresponds to) the rotor speed. Synchronous generators are internally (self) excited and so offer the potential to continue producing power whenever the grid is unavailable during blackouts. A separate DC excitation system is required as in a car alternator (synchronous generator). Grid interconnection is more costly and complex to ensure the system does not export power during grid outages.

“Black start” CHP systems can be started without grid power by using batteries (much like an automobile). Once up to speed, the CHP parasitic loads are powered through a “generator breaker.” A “tie breaker” is then engaged to connect the CHP to the full data center load.

ELECTRICAL INTERCONNECTIONS [7,8]

When connecting an on-site generator to a utility grid, the major concerns are:

- Safety of customers, utility personnel and the general public.
- Integrity of the grid – quality of service
- Protection of connected equipment

There are three modes of operation for CHP relative to the grid:

- Stand alone
- Isolated with utility backup
- Parallel operation with utility back up

The stand-alone mode requires the CHP system to operate completely isolated from the grid and redundant or back–up systems will be required to maintain reliability requirements during system failure and maintenance outages.

A grid-isolated CHP system with grid-provided back-up operates with either open-transition transfer or closed-transition transfer.

With open-transition transfer systems (break-before-make), the CHP normally serves the data center independent of the utility grid. Should the CHP system shut down, the data center completely disconnects from the CHP system before connecting to the grid and can cause a momentary power loss during the transition. When reconnecting to the CHP system, the data center is again completely disconnected from the grid.

With closed-transition transfer systems (make-before-break), the CHP normally serves the data center; but in the event of a CHP system shutdown, the data center does not completely disconnect before connecting to the grid (make-before-break) and may be connected to both the CHP and the grid simultaneously for up to one minute, with no power loss to the data center. This system requires more complex interconnection and synchronization during transition.

For CHP systems operating in parallel to the grid, the CHP system and the grid power the data center simultaneously, and the CHP system can operate in either export or non-export mode.

The export mode operation provides the flexibility to purchase supplemental power from the grid when economical and to sell excess power when available. The interconnection requirements for this arrangement are the most complex and costly. The interconnection ensures the CHP does not supply electricity to the grid unintentionally either with an induction generator or with circuitry that isolates the system from the grid automatically. Since the CHP system does not need to provide all the data center electricity requirements, the CHP system can be sized based on other than full data center electric requirements.

In the non-export mode, the CHP system is configured with reverse current relays that prevent exporting power to the grid at any time. Both the CHP system and the grid still simultaneously supply the data center, but the CHP must operate as “load following” to never produce more electricity than is required by the data center. The non-export mode, with two power supplies, offers enhanced reliability to the data center operations.

Each utility has its own interconnection protocols that differ, depending on the data center size and if the CHP system is connected to radial or networked electrical systems. Grid interconnection standards are governed by the Institute of Electrical and Electronic Engineers (IEEE 1547).

HEAT RECOVERY [7,9]

Generally, only thirty to forty percent of the inlet fuel is used to generate electricity, with the balance available for thermal loads. By recovering this heat energy from the exhaust stream and cooling systems, around 80 percent of the fuel's energy can be effectively utilized to produce both power and useful thermal energy. Most of the waste heat (45 to 55 percent) occurs in the engine exhaust and in the jacket coolant, which can be used to produce steam. Of this, engine exhaust represents 30 to 50 percent of the available waste heat. Smaller amounts of usable heat energy are available from the lubrication cooler but at a temperature too low for steam production.

Jacket Heat Recovery - Heat in the engine jacket coolant accounts for up to 30 percent of the energy input and can produce 190°F to 230°F hot water. Some engines, such as those with high-pressure or ebullient cooling systems, can operate with water jacket temperatures of up to 265°F.

Exhaust Heat Recovery – Engine exhaust temperatures can range from 720°F to 1,000°F, and can typically generate hot water of up to about 230°F or steam up to 400 psig. Only a portion of the exhaust heat can be recovered since exhaust gas temperatures are generally kept above temperature thresholds to prevent corrosion from condensation in the exhaust piping. For this reason, most heat recovery units are designed for a 250°F to 350°F exhaust outlet temperature.

Exhaust heat recovery can be independent of the engine cooling system or coupled with it. For example, hot water from engine cooling can be used as feedwater or feedwater preheat to the exhaust recovery unit.

CHP WITH ABSORPTION CHILLERS[6, 10]

Generally, CHP engines are about 40 percent efficient converting fuel into shaft energy compared to an average utility, which is 33 percent efficient. Central station electric production adds to these losses by five to fifteen percent in the distribution system between the generator and the data center end user. With a 40 percent efficient engine, the remaining 60 percent of energy takes the form of heat, which an absorption chiller can convert into chilled water. Absorption chillers can use this heat to produce chilled water to supply computer room air handlers (CRAHs) or even directly to liquid cooled racks. Coincidentally, the amount of chilled water a 40 percent efficient engine can produce this way is about equivalent to the amount of chilled water needed to cool the servers it powers.

Absorption chillers require about 50 percent larger cooling tower capacity and more pumping power than electric chillers since the tower must reject both the data center heat plus the heat created by chiller inefficiency (1+ 1/Chiller COP).

The type of absorption chiller used depends on the quality (heat content) of the waste heat stream produced by the CHP system. Microturbines and some reciprocating engines produce hot water sufficient to power single-effect absorption chillers, which require approximately 17,000 Btu/h of low-pressure steam or high-temperature hot water (190°F) to produce a ton of cooling (COP of 0.7). The high-temperature exhaust of gas turbines, other reciprocating engines and microturbines, and certain fuel cells (molten carbonate and solid oxide) can produce steam to drive indirect-fired, double- effect absorption chillers that require as little as 10,000 Btu/h of steam (COP of 1.2).

ON-SITE POWER GENERATION AND POWER RELIABILITY FOR DATA CENTERS[1, 7]

Data centers are good CHP candidate because they have high electricity and cooling requirements and operate continuously with nearly constant load. As mentioned earlier, a data center could have several sources of power with primary power provided by the CHP, grid-supplied back-up power from one or two feeders, and one or more standby diesel generators, which can also back up absorption chillers.

Data centers require reliable, high-quality power for IT operations. Even a momentary outage or lapse in power quality can take a data center down for several hours and cost millions of dollars in lost business.

The Uptime Institute, a data center research and professional-services organization, defined what is commonly referred to today as "tiers" or more accurately, the "tier standard," which describes the availability of data processing from the hardware at a location. The higher the tier level, the greater the expected availability

Currently, this standard requires on-site fuel storage for on-site generators defined as dedicated power sources. The standard focuses on diesel back-up generators and does not cover gas-fired CHP.

A report prepared for Oak Ridge National Laboratory in March 2009, “Opportunities for Combined Heat and Power in Data Centers,” identifies several interpretations of how CHP could integrate with data centers to enhance reliability. These include:

- In a basic Tier I facility, the CHP system could replace the diesel back-up generator
- In a Tier II facility, the CHP system could replace a portion of the redundant on-site power supply capacity
- In Tier III and Tier IV facilities, which often have redundant utility feeds, the CHP system could replace one of the utility feeds as an additional "economic alternative" and not as the defined "dedicated source of supply." Since utility feeds are not counted as a secure source of power, the replacement of one of these feeds with a CHP system should not affect Tier Classification. Alternatively, the CHP system could functionally replace a portion of the redundant generation capacity.

The report goes on to note that data center CHP system absorption chillers also need to be backed up with redundant parallel paths with redundant control systems, chilled water pumps, electric boards, etc. The report describes one design with the absorption chiller in series with a larger electrically operated screw compressor. When the absorption chiller operates, the electric chiller has a reduced inlet water temperature and operates at part load very efficiently. When the CHP system is down, the electric chiller picks up the full load. In Tier III and IV installations, thermal storage may be used for ride-through capability.

These redundant back-ups, utility standby, and seamless, fault-tolerant switchgear all add to the cost the facility. However, the CHP system contributes to reduction in the facility operating costs, unlike typical datacenter backup generators.

CHP AND DATA CENTER OPERATING COST AND ENERGY EFFICIENCY[11]

Many states have developed portfolio standards to increase the adoption of renewable, energy generation, energy efficiency, and alternative energy technologies. Forty states and the District of Columbia have some form of renewable portfolio standard, with twenty-one specifically specifying CHP and/or waste heat power (WHP) as eligible technologies and sixteen states specifically specifying CHP and/or WHP as eligible technologies under their energy efficiency resource standards.

ECONOMICS OF CHP IMPLEMENTATION[1]

Data centers require continuous power and cooling for high and relatively constant electric and thermal cooling loads, which makes them attractive for CHP applications. Data center cooling systems have to reject heat from IT equipment and also reject heat generated from inefficiencies in the critical equipment and from power conversion and distribution. For every 1 kW of power consumed in the data center, the cooling system must remove 0.28 tons of heat.

The total fuel utilization efficiency of the CHP plant comprises both the power generation efficiency and heat recovery efficiency. with the CHP system ideally sized to maximize the heat recovery potential from the CHP plant operation. When the CHP plant is sized to meet the IT demand, some technologies such as gas turbines provide more cooling than is needed, whereas fuel cells provide less cooling than is needed. Before implementing, the facility should be optimized with high energy efficiency infrastructure.

Table 3 provides a sample economic comparison of different CHP technologies.

SUMMARY

A summary of different options is shown below:

- Reciprocating engines and fuel cells can produce low-temperature hot water or low-pressure steam to drive a single-fired absorption chiller. Reciprocating engines are ideal for small CHP applications (less than 5 MW).
- Gas turbines and micro-turbines can produce medium- to high-temperature hot water and high-pressure steam suitable for double-effect absorption chiller applications. Although the micro-turbines have lower power generation efficiency, they have higher thermal heat recovery efficiency and recover more heat for supporting absorption cooling loads.
- With PAFC, only 50 percent of waste heat produces high enough for absorption cooling. The remainder of the waste heat is exhausted into the atmosphere. Fuel cells typically have better power generation efficiencies than gas turbines and reciprocating engines.
- Gas turbines are suitable for large CHP installations – typically over 4 MW. They have more favorable economics than reciprocating engines, fuel cells and micro-turbines.

CHP CONSIDERATIONS

- The CHP payback is more attractive for a data centers due to the high coincidence of electric and thermal loads. Consider sizing the CHP for the base thermal load to obtain highest efficiency.
- The selection of the prime mover should take into account the thermal-to-power (T/P) ratio. Reciprocating engines are more suitable for a T/P ratio of 0.5 – 1.0, whereas gas turbines are more suitable for a T/P ratio of 1 to 10. Both reciprocating and gas turbines are suitable options for data centers.
- Even with CHP, the facility will typically need diesel generators for back-up and to maintain the required levels of redundancy and reliability. CHP is a good option to reduce operational costs.
- Implement energy efficiency measures prior to CHP installation, as this will affect CHP sizing and potential to recover waste heat.
- Implementation of free cooling affects the potential to recover waste heat from the CHP for cooling purposes. Sizing of the CHP shall be evaluated to account for free cooling operation.
- Addition of absorption chillers in CHP applications adds parasitic loads in the form of absorber pumps/solution pumps and increased energy usage at the cooling towers. The energy penalty associated with using them should be taken into consideration when evaluating annual energy savings from CHP.
- Payback from CHP implementation is highly dependent on available incentives and rebates from utility and government entities as well as on spark spread (differential between the cost of buying electric power from the grid and the cost of fuel used to generate power using CHP). A detailed sensitivity analysis and financial modeling shall be conducted for a thorough evaluation of CHP feasibility.
- CHP is attractive when the economic value of power reliability is high for mission-critical applications such as stock exchanges, e-commerce platforms, etc.
- Include stand-by charges in the evaluation if the local utility has stand-by charges for CHP installations.
- Equipment overhaul and stack replacement costs shall be taken into account for TCO analysis.
- Site-specific constraints such as space availability; structural, sound and vibration considerations; proximity to natural gas connection; emissions requirements; grid inter-connection requirements; etc. affect the type and viability of the CHP installation.

CHP ARCHITECTURE

For most existing data center applications, CHP is commonly used in parallel to the utility grid while the diesel generators serve as a back-up. While the CHP plant may or may not be designed to meet the entire power demand for a facility, the system can be configured to maintain power to critical loads in the event of a utility grid outage. There are often added costs to implement this capability and tie CHP into the critical electrical supply. A system designed to supply the entire power needs of a data center facility during an outage may need to be oversized, which adds to the cost compared to the optimal design with the required redundant units [4]. The CHP plant should be installed with “black-start” capabilities if the CHP is designed to operate independently of the grid. Adequate controls and associated equipment such as inverters will be required to enable grid-independent operation.

In Tier III and Tier IV facilities, which often have redundant utility feeds, the CHP system could replace one of the utility feeds as an additional "economic alternative" and not as the defined "dedicated source of supply." Since utility feeds are not counted as a secure source of power, the replacement of one of these feeds with a CHP system should not affect tier classification. Alternatively, the CHP system could functionally replace a portion of the redundant generation capacity.

A sample of CHP architecture for a data center with 1,250 kW of IT load is shown in Figure 3 as a reference. In the sample architecture shown below, CHP is used to offset a portion of the utility electrical demand.

CONCLUSION

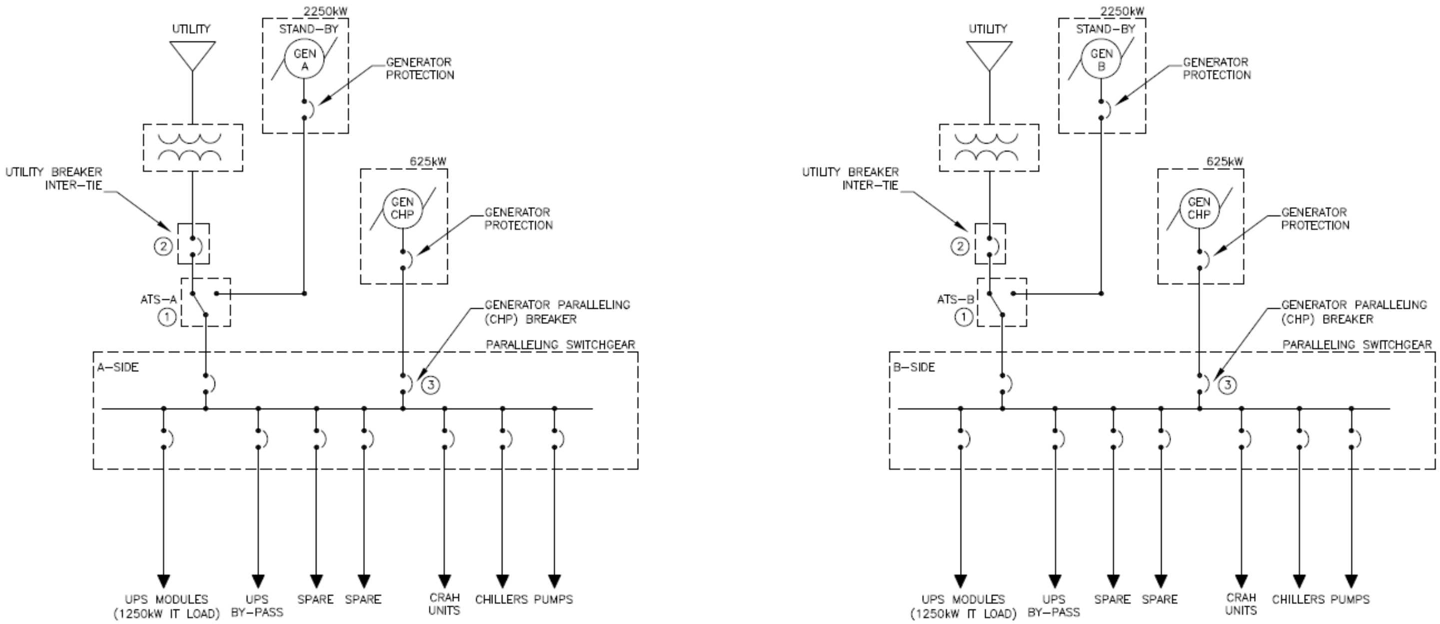
CHP offers data centers significant potential for energy savings while improving redundancy. Continuous electrical and thermal loads make CHP highly compatible for most data centers. A qualified consultant should be hired to conduct a detailed feasibility study that considers CHP technology alternatives, utility rates, applicable incentives and rebates, availability of natural gas, free cooling potential, site specific constraints such as emissions, sound, vibrations, etc.

The key to a successful CHP installation is commissioning. Critical infrastructure, including the electrical and the mechanical system, should be thoroughly commissioned after the implementation of a CHP project. In particular, the transitions into and out of the CHP plant operation shall be verified and parameters adjusted as needed to enable efficient and reliable operation of the data center.

TABLE 3: SAMPLE ECONOMIC COMPARISON OF DIFFERENT CHP TECHNOLOGIES

CHP System	**Reciprocating Engine**	**Micro-turbines**	**Fuel Cells - Phosphoric Acid**	**Gas Turbine**
IT Load, kW	1,250	1,250	1,250	5,000
CHP Size, kW	1,250	1,250	1,250	5,000
CHP Reliability/Uptime	95%	95%	95%	95%
Cooling Loads				
IT Cooling Load, Tons	356	356	356	1425
Miscellaneous Cooling Load, Tons	103	103	103	344
Total Data Center Cooling Load, Tons	459	459	459	1768
Annual Operating Efficiencies				
Power Generation Efficiency, %	40.0%	30.0%	40.0%	35.0%
Thermal Heat Recovery, %	45.0%	40.0%	40.0%	30.0%
Total Fuel Utilization Efficiency, %	85.0%	70.0%	80.0%	65.0%
Electric Chiller Efficiency, EER	24.0	24.0	24.0	24.0
Absorption Chiller Efficiency, COP	0.70	1.25	0.70	1.25
Chiller Type	Single Effect Absorber	Double Effect Absorber	Single Effect Absorber	Double Effect Absorber
Cooling Load Supported by CHP, Tons	280	594	125	1526
Heat Rate - HHV, BTU/kWh	8,530	11,374	8,530	9,749
Cooling Tons/kWh Produced	0.22	0.47	0.10	0.31
Data Center Power Usage Effectiveness, PUE				
Data Center PUE, CHP	1.36	1.26	1.41	1.32
Data Center PUE, No CHP	1.45	1.45	1.45	1.44
Utility Costs - Blended Rates				
Electric, $/kWh	$ 0.12	$ 0.12	$ 0.12	$ 0.12
Natural Gas, $/therm	$ 0.70	$ 0.70	$ 0.70	$ 0.70
Annual Energy Summary With CHP				
Onsite Electricity Produced by CHP, kWh	10,402,500	10,402,500	10,402,500	41,610,000
Cooling Electricity Avoided using CHP, kWh	1,166,947	1,911,511	518,643	6,350,733
Gas Consumed by CHP, Therms	887,370	1,183,160	887,370	4,056,547
Remaining Electric, kWh	4,588,593	3,546,367	5,107,236	16,354,161
Electricity Cost	$ 550,631	$ 425,564	$ 612,868	$ 1,962,499
Natural Gas Cost	$ 621,159	$ 828,212	$ 621,159	$ 2,839,583

O&M Costs	$ 215,061	$ 222,889	$ 211,166	$ 870,356
Total Annual Operating Costs	$ 1,386,851	$ 1,476,664	$ 1,445,193	$ 5,672,438
Annual Energy Summary Without CHP				
Electricity Consumed, MWh	15,924,651	15,924,651	15,924,651	63,044,747
Gas Consumed, therms	0	0	0	0
Electricity Cost	$ 1,910,958	$ 1,910,958	$ 1,910,958	$ 7,565,370
Natural Gas Cost	$ -	$ -	$ -	$ -
Total Annual Operating Costs	$ 1,910,958	$ 1,910,958	$ 1,910,958	$ 7,565,370
Total Annual Cost Savings with CHP	$ 524,107	$ 434,294	$ 465,765	$ 1,892,931
CHP Install Cost, $/kW	$ 2,000	$ 2,500	$ 5,000	$ 1,850
Absorption Chiller Install Cost, $/Ton	$ 1,800	$ 2,100	$ 1,800	$ 2,100
Total Install Cost for CHP	$ 3,004,808	$ 4,371,439	$ 6,474,359	$ 12,455,128
Simple Payback for CHP without Incentives (Years)	**5.7**	**10.1**	**13.9**	**6.6**



SEQUENCE OF OPERATION:

- NORMAL CONDITION UTILITY SOURCE AND CHP GENERATORS WORK IN PARALLEL.

LOSS OF UTILITY POWER:

(1) SHALL TRIP THE UTILITY INTER-TIE BREAKER AND THE CHP PARALLELING BREAKER.
(2) START STANDBY DIESEL GENERATORS.
(3) ACTIVATE ATS TO STAND-BY SOURCE AND FEED LOAD.
(4) CHP PARALLELING BREAKER SHALL CLOSE TO PARALLEL WITH DIESEL STAND-BY GENERATORS.

RETURN OF UTILITY POWER:

(1) CHP PARALLELING BREAKER SHALL TRIP TO OPEN POSITION.
(2) THE UTILITY INTER-TIE BREAKER SHALL CLOSE.
(3) ATS SHALL SWITCH TO NORMAL/UTILITY SIDE AND STAND-BY DIESEL GENERATOR SHALL STOP.
(4) CHP GENERATOR SHALL PARALLEL TO UTILITY (NORMAL CONDITION).

OPERATING MODE	(1) ATS	(2) UTILITY BREAKER	(3) CHP BREAKER
UTILITY	NORMAL	CLOSED	OPEN
UTILITY + CHP	NORMAL	CLOSED	CLOSED
DIESEL	EMERGENCY	OPEN	OPEN
DIESEL + CHP	EMERGENCY	OPEN	CLOSED

FIGURE 3: SAMPLE DATA CENTER ELECTRICAL ARCHITECTURE WITH CHP

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Shrenik Ajmera is an Engineering Manager at Willdan Energy Solutions. Mr. Ajmera has led the development of design solutions for various multi-million-dollar data center expansion, retrofit, and expansion projects across the nation. Mr. Ajmera has also completed several surveys, feasibility studies, and energy assessments to help customers mitigate risks, improve infrastructure reliability, and increase operational efficiency.

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