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EXPERIENCES WITH MICROTURBINE GENERATOR SYSTEMS INSTALLED IN THE SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT

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ABSTRACT

A comprehensive field data collection campaign is reported on in which operational data are being obtained from microturbine generators located in the South Coast Air Quality Management District (AQMD). The data obtained are archived in a SQL database, which provides the ability to look at various performance aspects as a function of many parameters interactively on the Internet. An overview of the program is provided along with details regarding the data collection and archiving strategies. To provide a framework relative to optimal operation of these systems in the region, economics associated with various operational schedules as a function of various rate structures in Southern California are provided. In addition to quantitative operational characteristics and performance results, some general end-user impressions of the technology and of the overall installation process are also documented. Details from three representative sites are presented.

BACKGROUND

Microturbine generators (MTGs) are being deployed worldwide for a number of applications. MTGs enable end users to generate their own power during times when power is in short supply, thus alleviating peak stress on the grid, reducing the likelihood of rolling blackouts that utilities may have to impose, and displacing emissions from the highest-emitting and least energy-efficient peaking units.

MTGs are available from a number of manufacturers including Bowman, Capstone, Elliott, Ingersol Rand, and Turbec, and represent an option for on-site power generation technology (known generically as “distributed generation”). MTGs can, in principle, be installed relatively quickly and require little maintenance. In addition to providing electricity, a heat exchanger can be used with the MTG to provide heating or cooling, which increases overall system efficiency (“combined cooling, heating, and power—CCHP”). MTGs are capable of operating on a variety of liquid and gaseous fuels and are generally considered to be “low emissions” devices.

Testing or evaluation of individual or limited numbers of MTGs has been completed or is underway (e.g., EPRI, (2002); Hamilton, (1999)). Many of the installations have been supported by the manufacturer or funding agencies as a demonstration of the technology. Additionally, some end-users are beginning to install and use systems either individually or through cooperation with a third party installer and/or energy service provider. The success of each installation is dependent upon a large number of factors, so it is difficult to develop a consensus view on the viability of the technology and the general strategy. The current project provides the opportunity to compile data from a large number of MTGs (207) and to provide a database which interested parties can use to guide choices they make relative to the consideration of MTGs for their applications.

The South Coast Air Quality Management District (AQMD) Microturbine Generator Project

In 2001, the South Coast Air Quality Management District (AQMD) committed substantial resources to providing Capstone MTGs to facilities in the four counties that the District serves. Funding for this program comes from excess-emissions settlements reached with the Los Angeles Department of Water & Power (LADWP) and the AES Corporation, and particulate emission mitigation fees paid by new power plants being installed in the District. As part of this program, the Advanced Power and Energy Program (APEP) at the University of California, Irvine (UCI) was contracted to collect and archive the internal system data from most of the MTGs installed

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through this project. All combined, 133 30-kW and 74 60-kW MTGs are included in this program. These MTGs have a capacity to generate about 7.6 megawatts of electric power, enough to power about 3,000 homes. A total of 207 MTGs will be installed in the counties of Los Angeles, Orange, Riverside, and San Bernardino. Installations have been completed and MTGs are online at numerous sites. All installations are expected to be complete in the near future. Figure 1 illustrates the locations associated with the project.

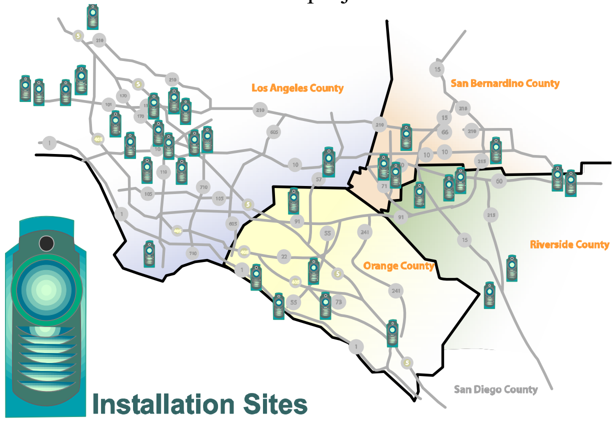


Figure 1. Monitored AQMD MTG Sites.

In April 2001, the AQMD offered MTGs to interested parties. Interested parties completed a short application intent form which listed basic information regarding physical proximity of grid and gas ties, physical space availability, understanding and consideration of potential noise issues, and ability to utilize waste heat from the MTG system. Initially, 50 sites were selected for receipt of MTG(s) based on the information provided. No detailed assessment was made of the installation requirements or the load profiles at each site. As a result, minimal “pre-engineering” was available. Most of the sites selected intended to utilize the MTGs for grid parallel operation and/or peak shaving.

OBJECTIVES

Collecting data from a large population of MTGs used in diverse applications yields a statistically significant amount of operational data and a breadth of data unparalleled by any other current MTG project. The information and data from this program are providing:

- examples of MTG utilization in a variety of settings
- better understanding of the long-term operational characteristics;
- documentation of the contribution to the energy grid.

MONITORING AND WEB REPORTING APPROACH

Collecting and monitoring the MTG data streams required the acquisition of a data acquisition PC, Capstone Remote Monitoring Software (CRMS), Internet connection via dial-up to an Internet Service Provider (ISP) or Ethernet IP connection and a few utility scripts to automate the data upload process which occurs daily. Data is uploaded to a central database server located at the Advanced Power and Energy Program (APEP) facility at UCI. Figure 2 illustrates the general approach taken.

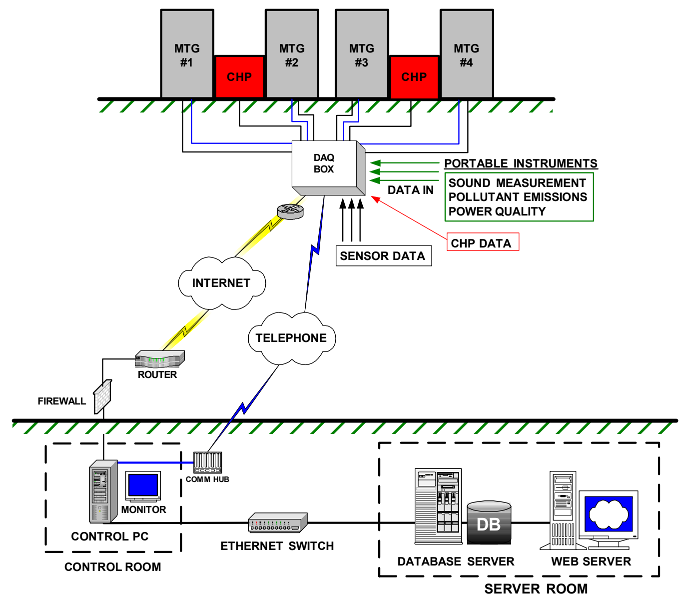


Figure 2. General Architecture for Data Collection and Display.

Data from each MTG are recorded at 1-minute intervals. The principal data consist of approximately 44 fields from CRMS software. In addition, some sites are outfitted with additional sensor information such as natural gas meter, natural gas temperature and pressure, electric meter, ambient temperature and relative humidity from National Instrument’s FieldPoint data acquisition hardware and LabVIEW software.

A Microsoft SQL Server 2000 database is utilized to accommodate large volumes of data (1440 rows consisting of 44 fields and additional sensor data, if available, for each microturbine generator per day) and to allow a Web-based strategy for the retrieval and display of raw and reduced information.

The Web based strategy applies a three-tiered approach to implement client/server applications (see Figure 3). It consists of a Microsoft SQL Server 2000 database server, Windows 2000 IIS Web server, and Web browser clients. The Web based data retrieval application is designed within a Microsoft .NET framework that allows for the use of current web technologies such as ASP.NET and PopChart. The Web application communicates with a SQL server via interactive Web page queries that allows requests for summary information of operating hours, kWh power produced, and % capacity for each month. The client has the ability to view historical data (day, week, month, quarter) for each MTG within a specific geographic location. The query process is quite simple: The client requests the parameter of interest, the request is sent to the Web server, the Web server retrieves the requested data from the database server, passes the summary data to the PopChart server and, finally, builds the dynamic Web pages based on the queried information for the client to view.

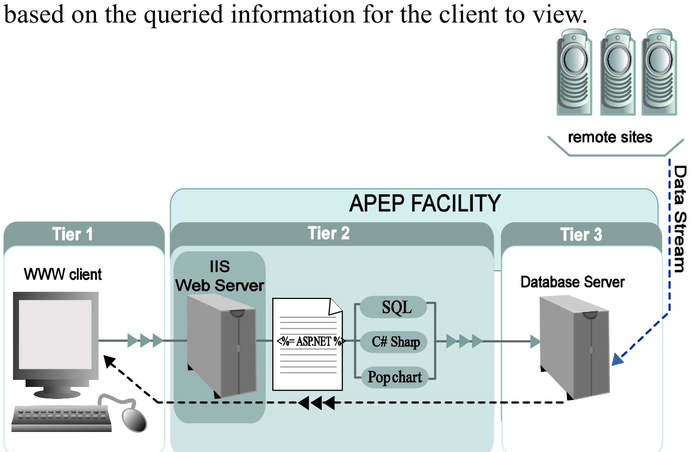


Figure 3. Overview of Three-Tier Software Architecture.

Table 1 shows three main tables in SQL database: Data from Capstone Remote Monitoring System (CRMS) software are stored in the **OperationalData** table, additional sensor data (if available) are stored in the **FieldPointData** table, and information about monitored Sites are stored in the **SiteMaster** table. Composite primary key pairs were set on "MachineCode" and "AcquisitionTime" fields to uniquely identify each record in the table as well as allowing for indexing of the table. Indexing allows faster access to specific information in a database table when a client requests the parameters of interest via the Web page.

Data Classification

Two classes of data are being obtained under the program, operational characteristics and detailed performance characteristics. As a result, the detail suggested by additional sensor input to the data acquisition (DAQ) box (Figure 2) reflects the ultimate amount of information obtained for any one MTG.

Operational Characteristics Data

The first class of data are basic operational characteristics. Despite the generous aspects of the AQMD program, detailed data acquisition equipment was not part of the scope. However, because all the MTGs were provided from the same manufacturer, basic "operational data" is available for all 207 MTGs through the CRMS system.

Table 1. Data Fields Maintained.

OperationalData
MachineCode
AcquisitionTime
EngineSpeed
TurbineExitTemp
CompressorInTemp
AmbientPressure
IncidentRecord
NumOfStarts
ServiceHours
SystemSeverityLevel
SystemState
PowerEnable
PowerDemand
PowerSupplyVoltage
StartCommand
FuelInletPLP
FuelOutletPLP
FuelInletPHP
SPVFuelExP
BatteryTemp
BatterySOC
BatteryVolts
BCDCBus
InvDCBusVoltage
OutputFrequency
OutputCurrentPhaseA
OutputCurrentPhaseB
OutputCurrentPhaseC
OutputCurrentPhaseNeut
OutputVoltagePhaseA
OutputVoltagePhaseB
OutputVoltagePhaseC
OutputPowerPhaseA
OutputPowerPhaseB
OutputPowerPhaseC
OutputPower
BatNoEqCharges
MeterPowerIn
MeterPowerOut
MeterVarIn
MeterVarOut
LFCInjectorState
TurbineNumber
MultiPackEnable

FieldPointData
MachineCode
AcquisitionTime
NatGasMeterTime
NatGasMeter
ElectricMeter
WaterMeter
NatGasTemp
MTGExhaustTemp
MTGInletTemp
WaterColdTemp
WaterHotTemp
EmissionsTemp
NatGasPressure
AmbientTemp
AmbientRelHumidity
EmissionsO2
EmissionsCO
EmissionsNO
EmissionsNO2
EmissionsSampleValvePos

SiteMaster
SiteID
AgencyID
SiteCode
SiteName
ShortSiteName
Address1
Address2
City
State
ZipCode1
ZipCode2
SitePhotoURL
SiteText

In Table 1, the fields associated with the **OperationalData** table and **SiteMaster** table are collected for all locations. These are data that are available directly from the CRMS system "user access port".

Detailed Performance Characteristics

Unfortunately, the data stream from the CRMS cannot be utilized directly to ascertain information of greatest interest to the user, namely efficiency. The end user economic benefit from the installation and operation of the MTGs can ultimately be seen in the actual utility bills paid. Complex rate structures and variation from region to region make generalization difficult even when this information is readily available.

Because of the desire to obtain information regarding efficiency in a manner that was disconnected from cost, additional instrumentation was added to a number of sites through support from Advanced Power & Energy Program and Southern California Gas. Adding a component that directly measured gas consumption provided a direct measure of efficiency.

At some of the sites, very detailed information is being obtained, including, at most, the various parameters illustrated in Figure 2. To accommodate this data collection, the general approach delineated in Figure 4 has been established. In this strategy, a combination of data collection architectures is utilized to port information into the SQL database. In this case, National Instruments LabVIEW is the principal software utilized.

RESULTS

Results are presented in two sections. The first is a summary of general observations and status as of October 2002. The second section provides more specific details regarding three of the installations.

General Status as of October 2002

Of the sites that were initially selected for installation of MTG(s), approximately one-third backed out as a result of the reality of the installation costs or other installation issues and alternative sites were found. As a result, 34 of the 50 original sites are currently participating. Of the 34 sites, 20 are currently operational at some level with 10 sites functioning in a reliable and consistent fashion. The first site was brought on-line in August 2001, 3 months delayed from the original schedule. Through the process of interviews and discussions with the sites, some general conclusions regarding possible reasons for the delays became evident.

General Installation Issues Encountered

Utility Approvals. Interconnection has been notorious for causing delays in the installation of small generation equipment (e.g., Alderfer, et al., 2000). Improvements have been under development and have even been put into place during the current program (e.g., California Rule 21, IEEE 1547). However, the majority of the installations required at least 3 months to get the interconnection issues sorted out.[1]

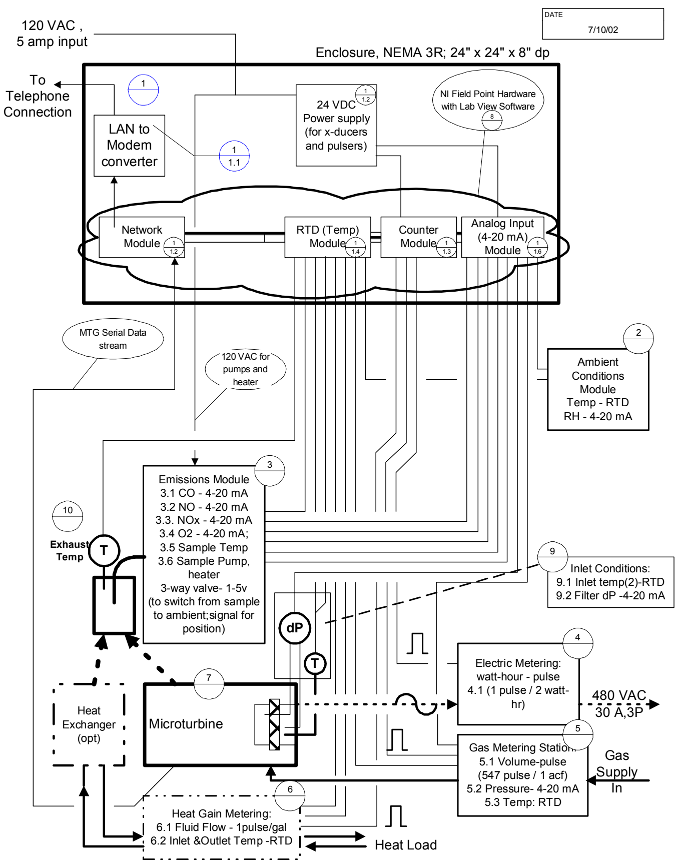


Figure 4. Data Acquisition Strategy for Additional Detailed Performance Characteristics.

In addition to electrical connections, confirmation of adequate gas flow capacity was also required. If shortcomings were identified, steps were required to apply for upgraded service with the gas company. This process, like the interconnection process, often required months to complete.

Local Building and Other Authorities. In general, it has been observed that local authorities tend to have a lack of knowledge regarding these devices. The extent to which MTGs fall under certain building codes and general safety codes is often not well defined. Efforts are underway to provide this type of information (e.g., Borbeley-Bartis, et al., 2000), but for the current program, issues relative to noise and a general lack of understanding of MTGs on the parts of various local authorities posed problems.

For applications at hospitals or public schools, other authorities with jurisdictions enter into the process depending

[1] Noteworthy is the adoption of a version of Rule 21 by Southern California Edison (SCE) in Sept 2002, which may facilitate faster installations in the SCE service district in the future. The Capstone Model C-60 MTG, Capstone Model 330 MTG, and PlugPower SU1PCM-059622 fuel cell are currently certified to meet Rule 21 Requirements.

upon the location. Examples included education institutes, which required additional approvals by the Office of State Architect (LA City College) and hospitals, which require additional approvals by Office of Statewide Health Planning and Development (OSHPD).

Air Quality Authorities. All of the MTGs under the program are located in the SCAQMD district. As a result, they fall subject to the permitting requirements associated with that particular district. Currently, the MTGs installed fall below the output size that is subject to permit requirements when operated on natural gas (AQMD Rule 219 (b) (1)). However, if the units are to be operated on landfill or digester gases, a permit is required. As of 1 January 2003, a new certification program (per California Senate Bill 1298) covers any small power plant below that covered by local jurisdiction.[2] Under this certification program, MTG equipment and other small fuel-burning electrical generators that are exempt from local air district permitting requirements are required to be certified that they meet stringent emission levels. MTGs sited at locations with landfill or digester gas as a fuel face additional costs associated with air quality permits. An example of this situation is given in the section on **Site Specific Findings.**

Cost. Although the MTGs were offered to interested parties along with some funds to support installation, as the potential for blackouts diminished in the summer of 2001, the reality of the need to authorize some financing either for balance of installation or for uncertain O&M costs became problematic for some of the sites. In the absence of a strong motivation such as imminent "rolling blackouts", the justification of covering the balance of installation costs was too difficult for some participants. The economics are further complicated by the uncertainty in future electrical and fuel costs. Most sites that have completed installation or are continuing to move forward have more certain fuel costs and/or motivation other than pure cost savings for proceeding.

General Economics of Operation

The economics surrounding the optimal operation of MTGs can be very complex. Assessing effective operation requires understanding the specific MTGs used (e.g. Capstone 30s, 60s, etc.), the ambient conditions that affect the MTG operation, and the applicable rate structures for both natural gas and electricity supply. The AQMD MTG project provided for the purchase and installation of the MTGs at various sites. As such, the economic analysis has focused on the operation of the MTGs as opposed to the decision protocol for purchasing MTGs.

For the purposes of this paper, three basic analyses are provided: one for each of the utilities covered in the AQMD project. These utilities include Southern California Edison (SCE), the Los Angeles Department of Water and Power (LADWP), and Riverside's public utility. One form of the analysis assumes the operation of a single 60 kW Capstone MTG without any waste heat recovery. A second form looked at the use of a combined heat and power (CHP) device. In these cases the projections combined the Capstone microturbine with waste heat recovery unit to provide a total thermal efficiency of 70.5%. The calculations have made some general assumptions about the total kW output of the MTG based on season. Additionally, the total output is reduced by 2.5kW, which is the approximate amount of kW used by the natural gas compressor. The assumed MTG output by season is shown in Table 2. These values were based, in part, upon experience operating the C-60 MTGs at UC Irvine early in the program.

Table 2. Assumed C-60 output vs Season.

Season	MTG Output\1
Winter	57.5 kW
Summer Full-Time	56.5 kW
Summer Peak-only operation	52.5 kW
Summer Peak and Mid operation	54.5 kW

\1 These values represent the average MTG output during the time which it is operated during each season. Because the peak-only operation occurs at the hottest period of the day, this will adversely affect the MTG output. This reduction is reflected by the assumed output of 52.5kW. By contrast, winter efficiency is the highest—57.5 kW.

The economic analysis also makes assumptions about operation and maintenance (O&M) costs and electrical efficiency. O&M costs are projected at $0.013/kW-hr of MTG operation. The electrical efficiency based on the lower heating value (LHV) of fuel is assumed to be 24.5%.

The basic inputs for the economic analysis include the gas price, the specific electricity rate structure (based on published rate structures from Southern California Edison (SCE), the Los Angeles Department of Water and Power (LADWP), and Riverside's public utility), the number of MTGs in operation, and the month of operation (used to determine appropriate rate schedule). The analysis identifies the cost savings associated with the use of the MTG at various natural gas prices.

The project analyzed SCE TOU-8 and I-6 rate structures. Each of these structures has price components that vary by season (summer is from June to September and winter is from October to May)[3] and by the time of operation. The rates used were effective on April 14th, 2001 for the TOU-8 and June 3, 2001 for I-6 both for service metered and delivered below 2kV (http://www.sce.com).

Figure 5 shows the cost savings associated with the use of the MTG under the TOU-8 rate structure under different operating protocols (continuous operation, peak-only operation, and mid and peak operation). The chart demonstrates that, for continuous operation, the MTG creates a cost savings when the natural gas price is below ~$0.80 per therm. The optimal operation, however, shifts from continuous operation to peak and mid-peak operation at ~$0.60therm—the point where the continuous operation line and the peak and mid-peak operation lines intersect. Similarly, the optimal operation shifts from using the MTG during mid and peak operation to using it only

[2] As of March 2003, the United Technology Fuel Cell PC-25 Model C and Capstone C-60 MTG are certified (see http://www.arb.ca.gov/energy/dg)

[3] Specifically, it is from the first Sunday in June to the first Sunday in October

during peak operation at ~$0.80/therm. Peaking operation would continue until the gas price reaches ~$2.00/therm at which point it is no longer cost-effective to run the MTG.

Because the end-user and the AQMD want to know the optimal operation of the units in terms of dollars saved, the following figures integrate the various operating possibilities into a single optimal use curve. A table is associated with each figure that defines how the MTG should be operated in order to realize the optimal cost savings for a given natural gas price.

Figure 6 shows the monthly savings by operating the MTG in the optimal manner for the four rates found in the SCE service area. It also shows the possible monthly savings when waste heat is utilized and clearly illustrates the associated economic benefit in terms of the dollar amount saved and the range over which the savings occur.

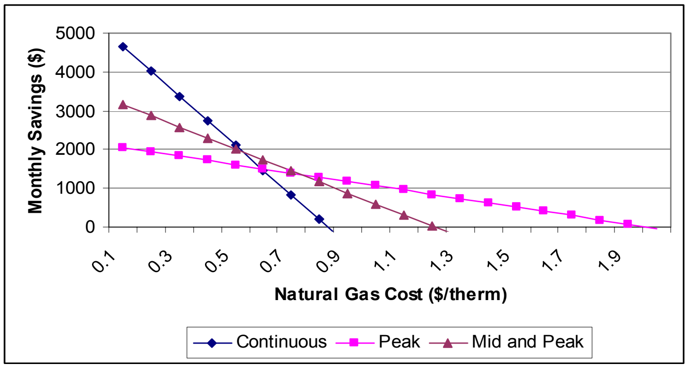


Figure 5. Monthly Cost Savings for Different Operational Scenarios for SCE TOU-8 Rate Structure.

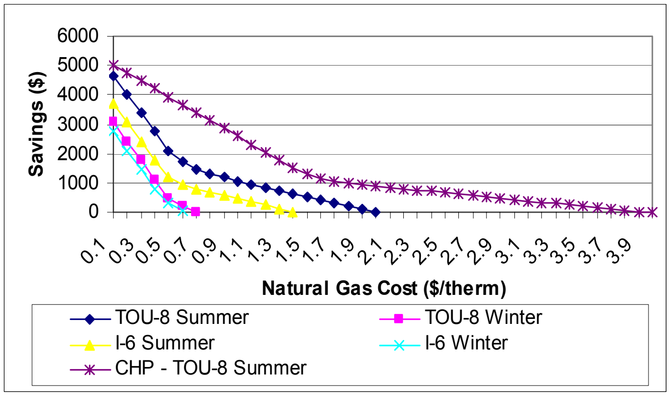


Figure 6. Maximum MTG Operation Monthly Savings (SCE Rate Structure).

Table 3. Recommended Operation Schedule for SCE Rates.

Operation Schedule	TOU-8 Summer	TOU-8 Winter	I-6 Summer	I-6 Winter
Continuous Operation	<$0.60/therm	<$0.50/therm	<$0.50/therm	<$0.50/therm
Peak and Mid-Peak Operation	$0.60 - $0.80/therm	$0.50 - $0.70/therm	$0.50 - $0.70/therm	$0.50 - $0.60/therm
Peak Operation	$0.80 - $2.00/therm	n/a	$0.70 - $1.40/therm	n/a
Do not operate	>$2.00/ therm	>$0.70/ therm	>$1.40/ therm	>0.60/ therm

Table 4. Recommended Operation Schedule for SCE Rates with Waste Heat Recovery.

Operation Schedule	TOU-8 Summer	TOU-8 Winter	I-6 Summer	I-6 Winter
Continuous Operation	<$1.50/therm	<$1.30/therm	<$1.30/therm	<$1.20/therm
Peak and Mid-Peak Operation	$1.50 - $1.80/therm	n/a	$1.30 – 1.40/therm	n/a
Peak Operation	$1.8-3.9/therm	n/a	$0.70 - $2.60/therm	n/a
Do not operate	>$3.90/ therm	>$1.30/ therm	>2.60/therm	>0.60/ therm

Table 3 and Table 4 summarize the desired operation schedule as a function of rate and cost of natural gas for electric generation only and with waste heat recovery, respectively.

Analysis was also done for LADWP's S-2 and S-3 rates. The rates were taken from the LADWP website in June of 2002 (http://www.ladwp.com). The LADWP also divides its rate structure into seasons (high season is from June to October and low season is from November to May). Figure 7 presents the monthly savings vs. rate and cost of gas for LADWP. It also shows the savings projection with waste heat recovery during the summer using the S-2 rate structure. It is noted that the S-3 rate is likely to be phased out.

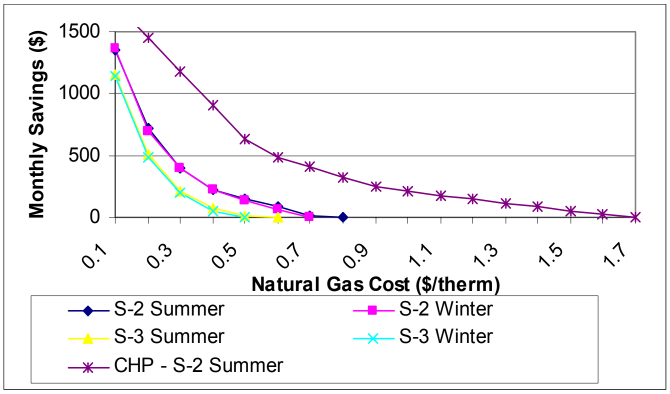


Figure 7. Maximum MTG Operation Monthly Savings (LADWP Rate Structure).

Table 5. Recommended Operation Schedule for LADWP Rates.

Operation Schedule	S-2 Summer	S-2 Winter	S-3 Summer	S-3 Winter
Continuous Operation	<$0.30/therm	<$0.30/therm	<$0.30/therm	<$0.30/therm
Peak and Mid-Peak Operation	$0.30 - $0.40/therm	$0.30 - $0.40/therm	$0.30 - $0.40/therm	$0.30 - $0.40/therm
Peak Operation	$0.40 - $0.80/therm	$0.40 – $0.70/therm	$0.40 - $0.60/therm	$0.40 - $0.50/therm
Do not operate	>$0.80/therm	>$0.70/therm	>$0.60/therm	>0.50/therm

Table 6. Recommended Operation Schedule for LADWP Rates with Waste Heat Recovery.

Operation Schedule	S-2 Summer	S-2 Winter	S-3 Summer	S-3 Winter
Continuous Operation	<$0.50/therm	<$0.50/therm	<$0.50/therm	<$0.50/therm
Peak and Mid-Peak Operation	$0.50 - $1.00/therm	$0.50 – 0.80/therm	$0.50 - $0.90/therm	$0.50 - 0.80/therm
Peak Operation	$1.00 - $1.60 therm	$0.80 – $1.50/therm	$0.90 - $1.20/therm	$0.80 – 1.10/therm
Do not operate	>$1.60/therm	>$1.50/therm	>$1.20/therm	>1.10/therm

As with the SCE rate structure, the LADWP rate structure divides into various segments based on the optimal period of MTG use as shown in Table 5.

The electricity costs in the LADWP rate structure are lower than in the SCE rate structure. The lower rates mean that MTG operation, as a whole, is less profitable within LADWP's rate district. Additionally, the summer and winter rate structures for the LADWP are very similar. As a result, the operating schedules are almost identical in both summer and winter periods for each of the rate structures.

Using a combined heat and power device improves the outcomes as indicated in Table 6.

Finally, the project analyzed the Riverside public utility's rate structure. This rate structure became effective on November 1, 2002 (http://www.ci.riverside.ca.us). Similar to SCE and the LADWP, the Riverside rate structure has different rates for both summer and winter usage. Riverside only has one rate structure for companies whose demand exceeds 150kW in a month. The analysis yields the results shown in Figure 8. This figure also demonstrates the use of CHP during the summer period.

Operation of MTGs in Riverside also has breaking points representing the price at which it becomes more efficient to change from full-time operation to some type of peak shaving operation. These results are summarized in Table 7.

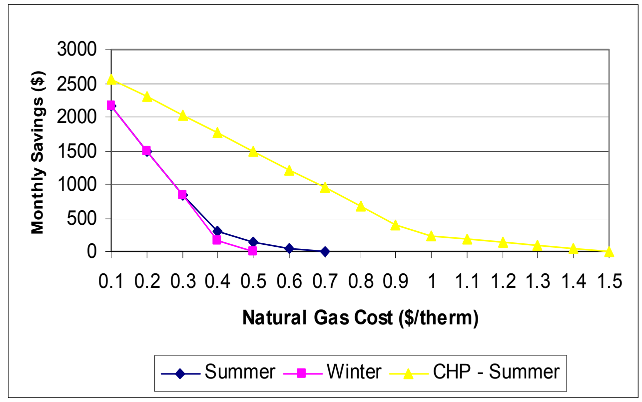


Figure 8. Maximum MTG Operation Monthly Savings (City of Riverside Rate Structure).

Table 7. Recommended Operation Schedule for City of Riverside Rates.

Operation Schedule	Summer	Winter
Continuous Operation	<$0.40/therm	<$0.50/therm
Peak and Mid-Peak Operation	$0.40 - $0.50/therm	-
Peak Operation	$0.50 - $0.60/therm	-
Do not operate	>$0.60/therm	>$0.50/therm

Table 8. Recommended Operation Schedule for City of Riverside Rates with Waste Heat Recovery.

Operation Schedule	Summer	Winter
Continuous Operation	<$1.00/therm	<$1.00/therm
Peak and Mid-Peak Operation	$1.00 – $1.10/therm	n/a
Peak Operation	$1.10 – 1.4/therm	$1.00 - $1.10/therm
Do not operate	>$1.40/therm	>$1.10/therm

The use of combined heat and power device gave the following operation parameters.

As each of the preceding charts and tables show, the economic savings associated with the MTG operation rests on several bases. In addition to the projected economics, the specific operation of the MTG may have a dramatic effect on the efficiency and, therefore, cost savings or expense associated with the operation of the MTG.

Site Specific Findings

As mentioned previously, 10 sites are operational at a level where detailed information can begin to be collected. Three sites are described in more detail in this section.

Cal State University Northridge (CSUN)

At the CSUN site, six 30-kW MTGs were installed along with 2 Micogen™ hot water generators (HWGs). The system was installed in a "multipak" arrangement, with 4 MTGs operating in conjunction with one of the HWGs and 2 MTGs operating in conjunction with the second HWG. Figure 9 shows the installation at the CSUN central plant facility which was constructed during the 2001 calendar year and commissioned in

December 2001. The site represented one of the first multiple-unit installations in Southern California and likely the first to combine the heat exchangers with MTGs in an educational institution in Southern California. The full installation cost was $108,000 ($18,000 per unit; $600 / installed kW). This cost is lower compared to other reported data at $16,500 per unit for electrical only and an additional $27,000 for the thermal recovery equipment (EPRI, 2002). This is attributed to the cost benefit of a multiple unit installation, which has been less typical in studies conducted to date.

Figure 9. Installation at CSUN Central Plant.

Not unexpectedly, issues were encountered during the installation and commissioning process. These were "moderate" to "minor" problems and are noted here as some of the areas to remain aware of from an end-user point of view. Perhaps the most significant issue was associated with the sizing of the gas transport plumbing. The original plumbing installation proved to be too small for the required gas flow capacity and the moderate delivery pressure (lower than originally expected) to operate the MTGs; the gas lines had to be replaced/upgraded to provide the added capacity. The installer rectified this at their cost.

In addition, the integration and operation of the heat exchangers proved problematic. Some challenges associated with integrating the heat exchangers, primarily identifying the proper tie-in location up-flow from the facility boilers were encountered. Also, some operational heat exchanger issues, including exhaust leaks from the heat exchangers proved to be a challenge and required resolution. The latter issues were covered under warranty at no added cost to the site.

Finally, challenges were encountered with the multipak controls system. The system has some issues communicating and controlling between the master and slave units. However, the specifics of the problems were not provided. It was mentioned that all of the issues were covered as warranty/commissioning issues and were not added costs.

The installation incorporates the HWG's to preheat the return feedwater for the campus' larger hot water boilers with the goal of either augmenting (by increasing water temp entering the boiler) or completely supplanting the existing boilers. The estimated campus demands for the two existing boilers ranged from 300,000 BTU/hr during the summer to 2,000,000 BTU/hr in winter. With 6 30kW microturbines, the potential heat capture of 200,000 btu/hr/unit appeared to be good match for the campus needs. The campus' system operates at nominally 60 psig and has a maximum operating temperature of 180 F, well within the capabilities of the HWG's.

The units are operated in a "peak shaving" mode designed to turn on at 10 am and turn off at 8 pm, Monday through Friday (10 hrs/day, 50 hrs/week), representing the low-peak and peak rates of LADWP (units are generally off during the base period). As such, the units are preprogrammed for "time-of-use" operation to automatically turn on and turn off at these times. During the operational period, the units operate at nominally 100% power.

In terms of operational experience, typical electrical efficiencies of 18.6% (based upon the purchased gas heating value of 1040 btu/scf) have been observed (based on Oct 02 to March 03). This corresponds to an efficiency based on LHV of the natural gas of 21.5%. The specifics of gas pricing structure are not known but the site operator has stated that the average cost of the produced electricity is approximately 11.5 cents/kw-hr. Based upon the planned hours of operation and the maximum nominal net output of the combined system of approximately 150 kW, the system has had an availability of 50% of the planned hours of operation. The system has been down due to a number of factors, including software and monitoring issues, and also some equipment failure issues.

One interesting observation is the way in which the system is configured; the water from the HWGs always flows through the boiler system piping. It has been found that running the hot water through the long lengths of boiler plumbing when the boiler is not fired leads to considerable cooling of the heated water. An improvement would be to install a bypass so that the high temperature water that exits the HWGs can be shuttled around the boiler when it is not fired.

The hot water was utilized to provide preheat to the plant boiler supply water, thereby displacing the amount of gas used in the boiler. Overall, the thermal loads were well matched with the output of the MTG. Though some issues arose with the instrumentation to measure the heat recovery from the two HWGs, estimates based upon spot checks of the HWG operation have shown overall system efficiencies (combined electric and hot water energy relative to heat input) on the order of $70 \pm 10\%$. However, the actual contribution of hot water to the campus, owing to the cold boiler phenomena previously described, has not been directly measured.

Rancho Santa Margarita Water District

Two Capstone 30-kW MTGs are installed with one Microgen™ hot water generator (HWG) at the Santa Margarita Water District (SMWD) Chiquita Water Reclamation Plant. Figure 10 shows a photograph of the installation at SMWD.

Figure 10. Installation at the Santa Margarita Water District digester plant.

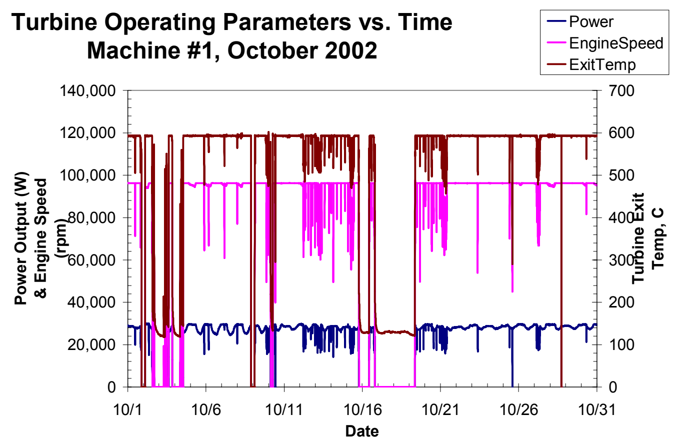
Though the MTGs were donated as part of the AQMD program in an effort to provide clean auxiliary power during periods of peak demand on the grid, the SMWD is satisfied with their operation, and they are in the process of independently purchasing two additional MTGs. An increased capacity Micogen™ unit will replace the current one when the third and fourth MTGs are installed so that heat from all four MTGs will be captured. The two current units were commissioned at the end of December 2001. Since then they have operated for approximately 6,000 hours (as of 10/15/02) and have generated approximately 300,000 kW-hrs of electrical energy. This adds up to typical operating cost savings of $4,000-$5,000 per month (consistent with results shown in Figure 6 for free fuel, although this particular plant is in San Diego Gas and Electricity territory). The MTGs are fueled by anaerobic digester gas from the nearby plant. A representative sample of the gas consisted of 36% carbon dioxide (CO_2) and 64% methane (CH_4).

Hot water from the HWG provides enough heat for the two anaerobic digesters on-site. Of the two boilers that were previously used to provide hot water, one is completely shut off and the other is on stand-by. Once the third and fourth MTGs are installed, the additional available heat will heat a future third digester and/or be used to dry out sludge, which would reduce transportation costs (of the sludge).

SMWD faced some challenges in installing and utilizing this equipment. Construction costs for installing turbines 1 and 2, not including change orders, was $83,666. This cost is consistent with other "per unit" data reported for CHP applications ($43,500/MTG per EPRI, 2002) even though it includes a sophisticated gas cleanup system. Other costs were associated with interconnection ($1,400 for four turbines), SCAQMD permits ($1,611 for two turbines) and emissions source testing ($8,815 to test one representative turbine). Another interesting observation is that the site is finding that contractors are reluctant to install the third and fourth MTGs for reasons associated with profit margins.

Figure 11 presents representative operational data for the site for the month of October 2002. The two MTGs exhibited somewhat different levels of operational characteristics. Machine 1 tended to be down more than Machine 2. In terms of strict availability (ratio of total operational time to calendar time), Machine 1 was available 83.6% of the time and Machine 2 97.3%. The longer downtime for Machine 1 is attributed to boiler testing at the site so is not really an indication of unreliable operation.

a) Machine #1



b) Machine #2

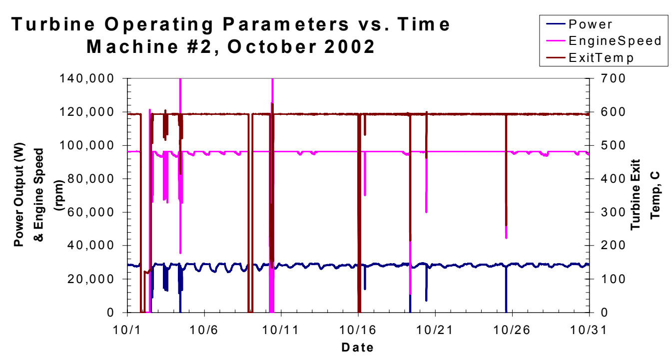


Figure 11. Operational History for SMWD MTGs for the Month of October 2002.

University California Irvine

At UC Irvine, three (3) C-60 MTGs were installed and commissioned on August 7, 2001 (Figure 12). The three units were operated on natural gas for 1 year as part of an evaluation of standardized test protocols for MTGs. Because UCI already had an interconnection agreement in place and natural gas was available at high pressure for existing combustion experiments, many of the installation issues described for other sites were not present. This was one factor that assisted the general installation. The cost of installation of the three MTGs at the UC Irvine site was $71,500 (or about $400/kW or $23,800/MTG). Of this cost, $49,650 (or about $275/kW or $16,550/MTG) covered the cost of 3 electrical meters, 3 gas flow meters, 3 sets of pressure and RTD transducers for the on site data acquisitions system, gauges, shut off protections, and the physical connections. The additional amount was required to develop plans and designs for electrical switching strategies that would fulfill the safety requirements of the campus. The additional process also led to several months of delays while the campus authorities approved the site. The installation costs without the additional cost for the campus approval process ($16,550/MTG) are quite consistent with other reported data ($16,500/MTG per EPRI, 2002). In the absence of the transducers for data acquisition which would not normally be required, the cost would be ~1,000 less per MTG.

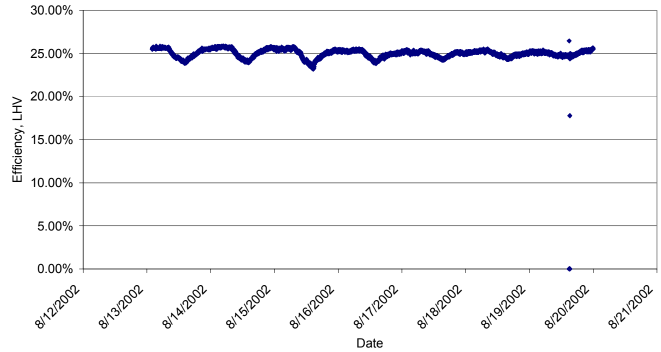
Figure 12. Installation at UC Irvine.

Operationally, during the period from 7 Aug 2001 to 6 Aug 2002, the three MTGs ran 83, 87, and 88% of the total calendar time ("strict availability"). On one unit, the "smart proportional valve" (SPV) failed right at the end of the 1-year campaign (7/16/02), but this was replaced within 48 hours. During the test period, one unit was available[4] 100% of the time expected (i.e., the unit operated 100% of the time it was requested to operate). The other units operated 99.4 and 94.5% of the requested time. The lack of availability in these cases was due to the SPV valve and a 24 VDC power supply failure/replacement, respectively.

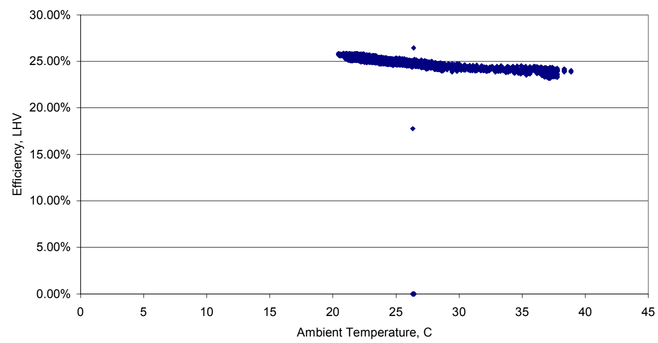
Due to the data acquisition system installed at the UC Irvine site (recall Figure 4), performance data are also being monitored. An example of how electrical efficiency varies during a one–week period is shown in Figure 13 along with an illustration of how efficiency is dependent upon ambient temperatures and relative humidity. These results are being utilized to verify derate curves and to provide comprehensive information on actual performance in the field as part of the overall program.

[4] Availability in this case is defined per IEEE 762 in terms of forced outage hours which does not penalize the MTG when it is not running unless the reason is due to a problem with the MTG itself.

a) Efficiency vs Time of Day



b) Efficiency vs Ambient Temperature



c) Efficiency and Relative Humidity vs Temperature.

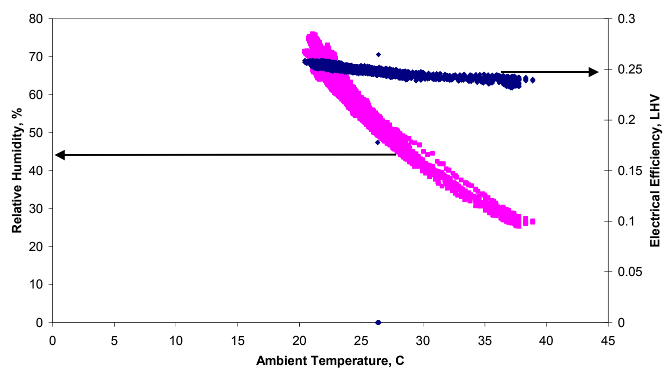


Figure 13. Representative Performance for one C-60 MTG as Function of Various Parameters.

SUMMARY

A comprehensive data collection campaign is underway in which operational data are being obtained from of MTGs located in the South Coast Air Quality Management District. To facilitate data storage and management, an SQL database has been implemented. A priori guidance relative to optimal operational schedules for Southern California Edison, Los Angeles Department of Water and Power, and the City of

Riverside rate areas has been suggested for comparison to actual experiences. To date, the number of units operational in the field is less than hoped for due to a number of (largely non-technical) reasons, including utility requirements, local authorities, cost issues, and uncertainty in the current market. At the sites where the units are operational, reliability has been acceptable. In one multi-unit installation at Cal State University at Northridge, software and control issues have led to challenges. Installations at UC Irvine and Rancho Santa Margarita have performed more reliably. Installation costs are ranging from $18,000 per MTG with CHP at a 6-unit site, to $24,000 per MTG for pure electrical generation, to over $40,000/MTG for a CHP system running on digester gas (including the gas clean up).

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