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Microgrid Energy Management System

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1. INTRODUCTION

A microgrid is defined as an aggregation of electrical loads and generation. The generators in the microgrid may be microturbines, fuel cells, reciprocating engines, or any of a number of alternate power sources. A microgrid may take the form of shopping center, industrial park or college campus. To the utility, a microgrid is an electrical load that can be controlled in magnitude. The load could be constant, or the load could increase at night when electricity is cheaper, or the load could be held at zero during times of system stress.

The microgrid utilizes waste heat from the generators to improve overall efficiency. The purpose of the Energy Management System (EMS) is to make decisions regarding the best use of the generators for producing electric power and heat. These decisions will be based upon the heat requirements of the local equipment, the weather, the price of electric power, the cost of fuel and many other considerations. The EMS will dispatch the generators and provide an overview of the Combined Heat and Power (CHP) system.

The Consortium for Electric Reliability Technology Solutions (CERTS) has a concept of the microgrid that is unique. In this concept, a minimum of overview control is needed for the generators. Instead, the generators are each programmed with control characteristics that allow them to function well together to provide a high quality source of power to the microgrid under a range of operating conditions. The generators are given only basic dispatch commands by the EMS. The "real time" control of the microgrid is handled by the characteristics programmed into the generators. CERTS is planning a test of this concept shortly. The control philosophy and the test are discussed in Section 2.

There are several commercially available Energy Management Systems that hold promise for the control and management of microgrid operation. Although no fully developed EMS exists today, manufacturers are already introducing into the market innovative products that can serve as building blocks to a highly versatile EMS. A list of these systems is provided in Appendix A.

Section 3 of the report addresses the functions the EMS will perform. The EMS, as defined for this report, is the system that dispatches the power output of the generators (e.g., microturbines, reciprocating engines, fuel cells, photovoltaic cells), and controls the heating and cooling equipment (e.g., boilers, chillers, fans, desiccant removal, dampers, etc.) The EMS for the initial CERTS lab test will only need a small fraction of this control capability. There will be no HVAC equipment to control in the lab test, only three microturbines and electrical load banks. The lab test EMS will only dispatch the microturbines, and may only supply power and voltage level signals. The EMS for the test will be a greatly reduced version of the final system. In the final system, the EMS will be responsible for decisions of when to operate each generator, at what power level, when to store energy, and what needs take priority.

The other sections of the report are summarized as follows:

Section 4 of the report discusses possibilities for utilization of thermal energy produced by the microturbines or other distributed generators. The report considers the significant relationships between generator heat production and the HVAC components that can make use of the heat. The report provides a review of various devices that can utilize the waste heat, such as absorption chillers and desiccant dehumidifiers. There is also a discussion on thermal energy storage.

Section 5 considers how the microgrid and EMS can optimize overall efficiency and reliability. First, a discussion of the energy requirements of the process and the efficiencies of the various components is provided. This analysis can be quite complex. Methods of optimizing efficiency, such as monitoring carbon dioxide and modulating outside air intake accordingly, are described. A discussion of opportunities and considerations in power quality and reliability is also provided.

Section 6 explores the possibilities for the microgrid to be involved in electricity and gas markets. For the microgrid to be fully utilized there must be a strong financial incentive for the owner to invest in a microgrid. This financial incentive will not fully exist until there is a market for the services the microgrid can provide to the distribution system. The development of such a market will take major institutional changes, but the reforms are occurring already in some parts of the nation. This section discusses some of the possibilities in the electricity market, the weaknesses in the natural gas market, and the needed reforms. After the market reforms are made, the range of valuable services described in section 7 would become a reality.

Section 7 touches on the range of opportunities for the microgrid to supply services to the distribution system. There are a number of significant services that would be natural for the microgrid to provide such as voltage regulation using reactive power supply, various reserves, blackstart, etc. This is potentially an exciting concept, however, as the study will show, certain concerns must be resolved. The study provides some detail as to the possibilities.

Section 8 describes the impact microgrids could have on the production of environmental pollutants, and the role the EMS could have in minimizing pollutant production. This section provides a brief discussion of possible algorithms, and important California Air Resource Board guidance. Future regulations may give credit for CHP in reducing net emissions.

Section 9 describes possible protocols and communication methods for EMS communication. A low cost, reliable standardized communication gateway must be developed.

Section 10 describes work performed at the Oak Ridge National Laboratory to develop predictive algorithms for modeling microturbines. Baseline performance data were collected on a 30 kW microturbine at various loads and backpressures. The backpressures were to simulate various types of heat recovery devices. The model that is being developed will provide a means of analyzing optimal system operation. This section provides a discussion of the general structure and basic steps for developing a Building Combined Cooling, Heating and Power (BCHP) system model.

Section 11 briefly lists the future research needs that became obvious during the preparation of this report. These are:

- The role of the market system to ensure that the microgrid is rewarded for functioning as a good citizen.
- Assessment of the beneficial impact microgrids can have on the distribution and transmission system.
- Analyzing benchmarking and giving credit for the effect of CHP and microgrids on the environment.
- Developing a low cost, reliable, standardized communication gateway.
- Developing and benchmarking a set of ancillary services that could be provided by microgrids.

2. EMS DESIGN CONSIDERATIONS AND TEST NEEDS

This section describes the many control functions that could be provided by the EMS and the two functions that have been selected for the CERTS microgrid concept.

2.1 What Are the Minimal Generator Control Functions that Must Be Provided?

There are many control parameters that could be considered for the EMS control of the microturbines. These include voltage, power factor, turbine speed, frequency, etc. Each of these parameters will be discussed below. The CERTS model of the microgrid is described in a report titled "Integration of Distributed Energy Resources: The CERTS MicroGrid Concept" and authored by: R. Lasseter, A. Akhil, C. Marnay, J. Stephens, J. Dagle, R. Guttromson, A. S., Meliopoulous, R. Yinger, and J. Eto [22]. In the CERTS model, the only two EMS dispatched parameters are power level and voltage. The power level must be dispatched by the EMS based on an economic assessment of fuel cost, electric power cost, weather conditions, and anticipated process operation. Voltage will normally be dispatched within a set band. (A description of the CERTS microgrid control philosophy is provided in Section 2.2.) A general discussion of the many parameters that could possibly be controlled and some of the major considerations is provided below.

Voltage Control

Voltage control seems like an obvious need, but in actuality there are several considerations. In conventional synchronous generator control philosophy, the control of the generator provides control of both the voltage magnitude and phase angle. By controlling the voltage magnitude and phase angle, the load and power factor of the microgrid could be controlled. Although this is a conventional synchronous machine capability, we only want the EMS to be in charge of dispatching voltage magnitude, and not involved in the control of the phase angle. The microturbine controller would perform the control of the voltage and phase angle. In addition, we want the EMS to only dispatch voltage on certain critical buses. The voltage on these buses would be controlled by the microturbine controller to satisfy the dispatched voltage. If the EMS also dispatched the power factor, an additional degree of complexity would be required. The power factor and voltage would have to be controlled rapidly as a function of load. It must be noted; however, when DER generators are aggregated in a microgrid and supply enough power to unload distribution feeders, they will cause voltage to rise on the feeders.

The CERTS goal is that the microgrid will have only a benign effect on the utility. In the future, the local distribution system may welcome voltage regulation from customer loads, and even pay for it. At the present time, however, the utility does not want to be burdened with additional control issues. Present interconnection rules do not allow voltage regulation, but call for generation at unity power factor. The first goal is for the microgrid system to appear to the utility only as a controllable load. Local electric utilities are justifiably concerned about uncontrolled voltage regulation. IEEE Standard 1547, the connection standard being developed for DER, requires that the DER generator follow the voltage and not attempt to change the voltage on the bus it is connected to. Therefore, the voltage signal provided by the EMS would most likely be a signal to follow voltage as it is sensed on a local bus. Voltage control is discussed in more detail in Section 2.2 below.

Power Factor

Power factor, or the amount the current wave lags behind the voltage wave, could theoretically be dispatched by the EMS. This introduces a distinct level of complication, as mentioned above, because the power factor of the load is constantly changing as motors are started and stopped, and the power factor supplied by the generator will have an effect on the voltage level.

Power factor control is a conventional capability in synchronous generators. Power factor control is not a capability of a simple induction generator. Induction generators can use switched capacitor steps to maintain power factor, and, many induction generators are supplied with interfacing power electronics. The power electronics can control the phase angle of the supplied current, enabling control of the power factor, and can also cancel harmonic distortion. This is an important capability, but this would add an unnecessary level of complication to the EMS. As discussed below, the CERTS plan is to have the power factor controlled locally at the generator, and not by the EMS.

Turbine Speed

Turbine speed is a variable that could potentially be controlled from the EMS. If speed could be controlled, the DER generator would be available to support expected load changes immediately. At least one DER turbine type takes time, as much as minutes, to ramp up in speed to supply more power. Others run at constant speed and use fuel supply changes to accomplish load changes. Obviously, turbine efficiency is a function of speed and fuel usage. Providing this detailed level of control of the turbine may perhaps be considered in the future, but at this time speed and fuel supply control just add an unnecessary level of complexity. The EMS should have more of a system overview role, and should only dispatch power level. The turbine's own control system will then decide how to operate the turbine in order to provide the dispatched power level at the optimum efficiency.

Frequency

Frequency, in conventional synchronous generators, is simply a function of the generator speed. In generators with inverter interfaces, like microturbines, frequency can be set wherever we would like. In the future, we hope that utilities will value local DER that can detect small frequency changes and "open the throttle" or increase power when frequency has drooped slightly. At the present time, however, this feature is not desired by utilities. In the stand-alone mode, frequency will be regulated, but only by increasing or decreasing power in response to load changes. The EMS will not dispatch frequency, because the goal is to maintain 60 Hz at all times.

2.2 The CERTS Model

In the CERTS model, we wish to make the operation of the microgrid as simple as possible from the viewpoint of controls and communication. We would like to build control characteristics into the dynamics of the system, so that feedback mechanisms that sense variables and provide commands will not be required for the EMS.

One of the objectives of the lab test is to test the premise of the CERTS model of microturbine control and operation. In this premise, the microturbine controller receives only two control signals from the EMS. These two signals are dispatched voltage and power.

Grid Connected

While the microgrid is connected to the grid, the only EMS control signals will be the real power output of the generation device and local voltage control. Any power delivered to the distribution utility is expected to be at unity power factor. There should not be any voltage control that would interfere with the normal distribution system voltage control measures (voltage regulators, shunt capacitors). Of course, if the distribution feeder is unloaded, voltage may rise; this rise, however, is not considered to be voltage regulation.

In the grid-connected mode, the dispatched power may be a set level, or it may be a command to load follow using a power sensor on the microgrid feeder that the microturbine(s) is connected to. The dispatched voltage is the voltage that is to be regulated within a set band on certain buses within the microgrid. The microturbine will not be allowed to regulate the interconnection bus voltage in the grid-connected mode, but this voltage regulation is needed when the microgrid is in stand alone. The microturbine will be able to regulate voltage on certain of the microgrid's own buses, within limits, even when providing a set power level, by controlling output power factor. This voltage regulation within the microgrid will only be provided on the buses that are connected to microturbines.

In the grid connected mode, the microgrid could appear as either a constant power load, or it could shave load peaks, or it could vary the load purely as a function of total coincidental load within the microgrid. The voltage on certain critical buses within the microgrid would still be regulated, however, in response to dispatch signals from the EMS.

Stand Alone, Grid Independent (Islanded)

While operating isolated from the grid, the EMS control signals will still be power and voltage. Frequency and reactive power flow will be controlled by the microturbine controllers. These will have to be fairly fast control signals to be sure that loads and generation are always balanced. It is hoped that the droop controls will do most of this at the generator, with the EMS control system just communicating the desired setpoint. There will also be a need for the EMS to perform rapid load shed within the microgrid to balance generation and load.

In the grid independent mode, the microturbines would operate with a frequency droop characteristic (power output is increased when a frequency droop is sensed) so that they could respond to regulate frequency within the microgrid. In both the grid independent mode and grid connected modes, the microturbines would operate with a voltage droop characteristic (reactive power output is increased when a voltage droop is sensed) so that reactive power flow is controlled within the microgrid. Speed, voltage and phase angle would not need to be under the direct command and control of the EMS. Instead, they would be managed by the microturbine controller.

Microturbine Controller

The microturbine's controller monitors the power flow on the feeder, which varies as a function of load, and controls the power output of the microturbine to keep the power flow to the feeder constant at the dispatched level. Or if there were two microturbines on a feeder, one could provide a set level of power and the other could load follow. The microturbine's controller also monitors the feeder voltage, and regulates the voltage to keep it within the dispatched band. In this way, the microgrid can draw a constant power load from the distribution system, and at the same time, regulate voltage within the microgrid.

Voltage Regulation

The microturbine will be able to regulate voltage on certain buses within the microgrid. The microgrid will not, at this time, regulate voltage on the distribution system.
The voltage on the distribution system feeder to the microgrid will rise when the feeder is unloaded. The feeder could be unloaded either because load is dropped from the microgrid, or because the microgrid is powering its own load. This voltage rise is not to be considered as active voltage regulation of the feeder. Performing a service of voltage regulation is a natural and logical function of the microgrid, and would be a highly efficient method of improving distribution system performance. In the future, voltage regulation, and a host of other services, will be provided by the microgrid for the distribution system. They will not be considered for this test, however.

EMS Control of Thermal Loads

Should the thermal loads take priority over electric power output from the microturbines? One aspect of the control model that will be a key decision factor later in the development of the full scale EMS is that the heat output of the distributed generators is often the priority parameter dispatched by a conventional building EMS, and the power output is considered to be a side benefit that is used in whatever quantities it may be available. Conventional wisdom has it that in typical cogeneration applications, the heat is actually the primary commodity, and the power is a side benefit. However, the power is often worth more than the heat. In actual practice, the decision will be based on the needs of the owner.

Operation at Best Efficiency Point

Another aspect that will be included in future, larger scale models is the control of the microturbines so that they operate at their best efficiency points. For light load conditions, it would be better to have fewer microturbines running, but running at rated load, than to have several microturbines running at partial load. This is because the microturbines are more efficient when operating at rated load. The decision of how many machines to run, and at what load, can best be made by the EMS, because the EMS has knowledge of the process condition, the weather forecast, and the production schedule.

Energy Storage

A final control feature of the future, larger scale EMS will be managing non-critical loads so that they can serve to provide reserve power within the microgrid. It is anticipated that not all "reserves" will come from energy storage. Energy storage devices, such as batteries and ultra capacitors, will be ideal for short term power requirements (seconds to minutes) for such needs as fault current, motor starting, etc., but for longer term needs, such as 10 minutes to one hour, it will be useful to have "reserves" by shutting down non-critical loads that can be stopped for this period of time with no deleterious effect. These non-critical loads would be powered from the buses with the microturbines, and would be planned by the EMS as a source for reserve power when needed.

CERTS Initial Testing

The CERTS initial testing is intended to explore the concept of the electrical operation of the microgrid using only the EMS dispatch signals and the microturbine frequency droop controlling real power and the voltage droop controlling reactive power to assess the ability of this system to provide high quality power for a diverse load using only a minimum of generation sources. Thus in the initial CERTS testing, the heat output will not be used. The EMS will only provide the dispatched power and voltage signals. The microturbines will respond to voltage and frequency droops as programmed and the operation of the system will be evaluated.

In the long-term future, there are a number of ancillary services, or reliability services, that microgrids could provide to the distribution system. These include voltage regulation, reserve power, black start, and controlled islanding. These services are discussed further in Section 7. These services could be grouped in the category of distribution/grid future interface. The initial microgrid test program will only focus on services that could be provided within the microgrid itself, services such as power quality and reliability, heat production, higher operating efficiency, and lowering overall pollutant emissions to the environment.

2.3 Operational Philosophy of Current and Future EMS Systems

Most current Energy Management Systems were originally designed to control Heating, Ventilating and Air Conditioning (HVAC) processes and are being expanded to include the energy needs of the manufacturing process, be it ice cream or textiles, and the control needs of distributed generators. They are equipped with expert systems to analyze large numbers of variables with extensive algorithms. The use of these systems to control distributed generation is relatively new, and most manufacturers are just getting started in addressing the needs of distributed generation. Only a few are directly addressing microgrids.

EMS systems of the future will manage information to improve overall profitability, not just simple process operations. Manufacturing and service companies will be able to maximize their returns while at the same time, maintaining high quality and minimizing downtime. EMS systems now monitor for equipment degradation, assist in diagnosing process problems, and analyze overall process efficiencies. They provide advice to the system operator as to desirable set point and other process changes, and can make the changes themselves when authorized, or can simply provide guidance to the operator to maximize efficiency and availability.

A large office building, or office park, or industrial plant may have several process control systems for systems such as the heating, ventilating and air conditioning (HVAC), and industrial processes such as aluminum smelting or ball bearing grinding. An EMS will act as an overview director of these control systems in addition to dispatching the local generators and energy storage. The EMS would receive information from the process control systems, and provide control commands for the optimal operation of the systems.

The EMS will provide an overview of the process control systems, focusing on energy consumption, and analyzing energy savings opportunities. The EMS will monitor energy consumption by type of day (workday vs. off-hours), by process condition (making steel vs. shutdown for maintenance), and by weather. The EMS will also monitor sub-metered electrical consumption for fans, pumps, lighting, process equipment and other major equipment. It will use this information to assess chiller and boiler efficiencies under full and partial loads. [1] The EMS will be able to manage operations to take advantage of real time market pricing of electricity and fuel, to optimize the use of onsite energy resources, and to utilize energy storage in the most efficient manner.

Ideally, the EMS provides only the needed information, and does not overwhelm the operator with extraneous information. In addition, the EMS allows other employees, or other authorized persons, to query the system to obtain information on particular parameters or operating conditions in which they may be interested.

The EMS will allow the user to program the basic operation and set points of the various process systems, and will also allow the user to enter their own algorithms, or empirical models, to maximize overall efficiency. As discussed later in this paper, the number of basic considerations to be incorporated into the algorithms can be large, including such factors as the present and forecasted weather, electricity and fuel prices, manufacturing backlog, contract arrangements to supply ancillary (reliability) services, building occupancy needs, etc. In some cases, the EMS will provide its own suggested algorithms, especially for HVAC control.

In many cases, field data is collected over a wireless RF network. It is essential that the EMS be capable of accepting field data from a wide range of control devices and controls manufacturers. Information from transducers and other monitoring devices is needed in the form of fluid and gas flows, pressures and temperatures, voltage, current and power, all of which may be provided by newer, digitally based equipment, or older equipment operating on pressure or current signals.

2.4 Other Control Considerations and Test Philosophy

There are several manufacturers of communication and control systems designed expressly for DER control. Typically, these controllers communicate through a version of an RS-485 (Digital Computer Based) Link or an Ethernet type link or both. They contain software to perform generator synchronization, calculation of real power, control sharing of reactive power, control sharing of real power, soft loading and unloading, base load control, protective relaying, and other functions. With the needed communication links and sensors, these systems can also monitor power flow at remote locations, monitor power quality at remote locations, and real time power market rates.

Control systems have long been available for larger DER generators that use synchronous generators driven by reciprocating engines. The reactive power output of a synchronous generator is controlled by simply controlling the generator field excitation. There are also control systems designed for microturbines. The power output of microturbines is conditioned by a power electronics interface. Here, the voltage is controlled precisely to virtually eliminate circulating current or reactive power between generators operating at different voltages.In the future, the power electronics interface may be capable of providing various power factors as needed to regulate local voltage.

In conventional DER generator control designs, typical small DER generators are controlled to operate either in the grid-paralleled mode or in the stand-alone mode. The grid-paralleled mode means that the generator supplies power only when utility voltage is present. The generator follows the prevailing grid voltage and frequency. The generator senses output voltage and quickly disconnects when the voltage goes above or below preset limits. This is to ensure that the local generator does not energize utility wires de-energized by the utility, and that the local generators will not interfere when the utility's own control and protection system is dealing with a contingency. In addition, the local generator will not cause a local energized island when the utility system is de-energized. The local generator is equipped with protective relaying to ensure that these functions are accomplished. When operating in the grid paralleled mode, the generator can typically be set to either follow the local (in house) load, or to provide a set amount (kW) of power. When operating in the stand-alone mode, the typical small DER generator will follow the load and try to maintain voltage within a set band.

The typical small DER generator manufacturers also offer options for remote monitoring systems. These systems can communicate using a serial port or modem, and can control up to perhaps 40 generators. At his PC, the operator can issue generator start, stop and power level commands. He can also obtain information such as speed, voltage, power level, etc.

Many of the manufacturers of control and communication systems state that they can manage multi-vendor control devices. Their systems can integrate devices regardless of manufacturer, platform or communication standard. In general, however, the "generic" control systems like Wonderware do better at communicating with a wide variety of equipment. In general, the HVAC types of EMS systems are typically better at sensing and controlling the equipment manufactured by their parent HVAC control company. A list of many of the manufacturers of control and communication systems is provided in Appendix A.

The Capstone Remote Monitoring System

As discussed below under Vendors and Systems, Capstone, the simplest approach for the test EMS may be to use the Capstone Remote Monitoring System (RMS) to simulate the EMS during the test. The EMS will provide remote dispatch, control and monitoring of the microturbine. The RMS communicates with the microturbine either though an RS-232 link or the Internet.

The present Capstone operational philosophy of the RMS is as follows: When in the grid-connect mode, the RMS allows the operator to set the power output in kW and the on/off times. With a separate power meter, the operator can set the turbine to either load follow, or to keep the utility load to zero, or to keep the utility load at a preset level. When in the stand alone mode, the voltage and frequency can be set as desired, and the unit will load follow; the power output cannot be set.

The operational philosophy that is proposed for the CERTS test is as follows:

When in the grid connect mode, the RMS will allow the operator to set the power output in kW for either a constant power output or load following using a separate power meter. In addition, the RMS will allow the operator to set a voltage and frequency setpoint and band. Note that while in grid-connect mode, the microgrid will not be able to change the system frequency and may only be able to make small changes in feeder voltage. Because of this, there may not be any frequency droop for the control system to respond to. The RMS will allow the operator to set a voltage and frequency droop characteristic. With this characteristic, when the voltage or frequency droops slightly from the setpoint, the turbine throttle will be opened, and the turbine will produce more power until the voltage and/or frequency is restored to the setpoint. The local turbine control will have the authority to make this change in response to sensed droops. The droop characteristic may be quite different from that used on large conventional generators. It is possible that a proportional control may be required. The test will help to determine what is needed.

In large power systems, turbine governors are designed to increase the power when the frequency drops. The governor droop is expressed as a percentage, which is the percent of frequency change between no load and full load on the unit. Five percent is a typical droop characteristic. A 5% droop means that if the frequency drops by 5 percent (a huge amount), the power will increase by 100%. By setting machines to have the same droop characteristic, the machines share equally any increase in load, and they don't "fight" each other. In a large power system, some units are designed to provide frequency regulation with the droop characteristic, and some are simply operated at fixed load for maximum efficiency.

When transferring to the stand-alone mode, loads will have to be shed in the microgrid until the load equals the total generating capacity of the available microturbines. After this, one microturbine will operate with a fixed base load setpoint, and the other will load follow, or they could both load follow in a fixed power ratio.

One of the challenges in the proposed philosophy is that of reactive power flow. When both microturbines are operating in a droop mode, their voltage phase angle and magnitude will likely be different. This means there will be current flowing in the feeders due to the difference in voltage. The current will cause heating of the feeder cables and additional voltage drop in the cables. The control systems of the small power systems using synchronous generators sense and actively manage this reactive power flow.

Voltage oscillations are another common problem in small power systems as the turbine throttles open in response to droops, the voltage is overcorrected, and excessive reactive power flows. The goal of the proposed test is to determine if the reactive power flow would be minimal if the microturbine were operating with the correct droop characteristic and each microturbine was controlling voltage in a manner that did not result in oscillations or reactive power flow. Providing only the voltage and power signals to the microturbine would allow for an elegantly simple control system. A minimum of sensors would be needed.

2.5 Candidates for the CERTs Test

Major potential vendors for a comprehensive EMS system are listed and described in Appendix A.

The list of vendors in Appendix A includes manufacturers of control systems that evolved from a range of sources. Some of them are HVAC control manufacturers, such as Honeywell or Robert Shaw, who now include control of distributed generation in their product capabilities. Some are specifically designed for the control of large distributed generation systems using synchronous machines, some are designed only for the control of the manufacturer's own microturbine, and some are totally flexible process control systems that are adaptable to any form of computer based communication as well as providing modules for wireless, telephone and other communication types.

The key deciding factors for the test EMS are:

- Microturbines are being tested - not large turbine generators, and the only control signals being provided to the microturbines are voltage and power.
- This test is not going to involve simulation of market conditions, control of waste heat and HVAC equipment, etc.
- The test control platform needs to be flexible to adapt to test changes and should have a graphical interface so that a "control panel" can be created on the monitor.
- The test control platform needs to be able to communicate easily with the microturbines.
- The limited scope of the initial test does not warrant a large expense.
- The test EMS does not need data acquisition capabilities because the test performer will provide the data acquisition that will collect and store the many variables to be monitored during the test.

Because of the limited capabilities required of the EMS during these initial tests, and because of the desire to "keep it simple", it may be best to just use the Capstone Power Server CPS 100, or a similar relatively simple system. The CPS 100 will provide networking via one RS-232 connection or a modem. There is also Internet command via TCP/IP. There is an improvement that Capstone must make, however. Presently, when a Capstone turbine is in the stand-alone mode, it acts as a voltage source. That is, it regulates voltage and frequency and supplies current as needed by the load. When the turbine is in the grid connect mode, it acts as a current source, that is, it follows the voltage and frequency of the grid, and regulates the current, or power output, to a preset value. Capstone has to modify their controller so that the turbine can regulate voltage when it is in the grid connect mode. In addition, the controller must provide a "droop characteristic" so that the microgrid will function to regulate power flow. These changes probably need to be made in the turbine control software and not in the CPS 100 since the turbines do not have these functions presently.

The Capstone microturbines already provide a wealth of status information through their existing network interface. A partial list of the information available is given in the list below:

Presently Available Capstone Microturbine Status[1]

• Engine Speed	• Turbine Exit Temperature	• Ambient Pressure
• System Severity Level	• System State	• Fuel Energy Flow BTU/sec
• DPC Board Temperature	• Power Demand (W)	• Power Supply Voltage (V)
• Fuel Inlet Press LP (kPa)	• RFC Temperature	• RFC Speed
• Bat Temp	• Bat Heatsink Temp	• Bat Board Temp
• Bat Volts (Vdc)	• DC Bus Volts (Vdc)	• Output Frequency (Hz)
• Output Current Phase A (A)	• Output Current Phase B (A)	• Output Current Phase C (A)
• Output Current Neutral (A)	• Output Voltage Phase A (V)	• Output Voltage Phase B (V)
• Output Voltage Phase C (V)	• Output Power Phase A (W)	• Output Power Phase B (W)
• Output Power Phase C (W)	• Output Power (W)	• Output Current Limit (A)
• Gen Direct Current (A)	• Gen Quad Current (A)	• Gen Direct Voltage (V)
• Gen Quadrature Voltage (V)	• Gen Speed Command (RPM)	• Brake Voltage Command (V)
• DPC Gen Temp	• Brake Temp	• Bat No. Eq. Charge
• Meter Watts In (W)	• Meter Watts Out (W)	• Meter VAR in (VAR)
• Meter VAR Out (VAR)	• LFC Injector State	

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[1] Unless it has changed recently, the Capstone software does not report power factor or VAR however these could be calculated from voltage, current and power or obtained using separate instrumentation.

3. OVERVIEW OF THE ENERGY MANAGEMENT NEEDS OF THE MICROGRID

This section addresses the range of energy management functions the EMS could perform such as local control of generation and various subsystems including building process control, HVAC, water heating, etc. Also discussed are possibilities for the storage of electric energy, meeting the electric power quality needs of industrial operations, and opportunities for supplying ancillary services to the local utility. There is a significant and important potential for microgrids to level electrical load peaks and provide other services to the utility. The EMS for the initial CERTS lab test will only need a small fraction of this control capability. In the final system, the EMS will be responsible for decisions of when to operate each generator, at what power level, when to store energy, and what needs take priority. Finally, this section discusses the possibility of supplying some energy services to the electricity market.

3.1 Distributed Energy Resource (DER) Control

The distributed energy resource (DER) may consist of various power generation technologies including microturbines, fuel cells, reciprocating engines, photovoltaic cells or other generation types. The DER typically supplies both electrical energy and heat. Some DER use essentially free fuels like sunlight or landfill gas. These will be usually operated at maximum power level whenever the fuel is available and the load can use the power, but others, which use natural gas or hydrogen, may only be run when it is most economical to operate them. Some DER generate excess heat, which can be used in building or industrial processes, such as heating domestic hot water. The determination of when to operate each DER, and at what power level, may turn out to be a rather complex decision depending on the cost of fuel, the cost of the electric power that is deferred, the cost of the heat that is deferred, the impact of the emissions both from the DER device and the deferred emissions from the central generator. The goal is to ensure that the DER not only saves energy but also acts as a good citizen.

Another interesting consideration of DER control is that the demands for electric power and heat may not occur at the same time. Which demand should the DER respond to? In addition, there may be other services that the DER can provide. These may include voltage regulation, standby power, and ride through for voltage sags from the utility. Depending on location, time and other circumstances, some of these services may provide such a huge benefit that their value may dwarf the payback from heat or kilowatt-hour reduction.

The final consideration is the role of the market system. The market system of the future will be discussed. As in the operation of the DER, there are many competing demands, which must be assessed by a properly designed market system so that it sends the right signals to those bidding in to it. The owner of the DER should be expected to optimize the economics of his installation. The operation of his unit will be directed not only by his own needs for power, heat and back up power supply, but also by the opportunities provided by the market. For example, during shortages of natural gas, it would be ideal if gas fired generation were used less, and generation fueled by other fuels or renewables were used more, to minimize the demand on the gas supply. Ideally, the market system would be designed with this sort of function in mind. Most importantly, there may be occasions where the local distribution system is in need of voltage regulation or reserve power. When these are needed, the price should be such that DER owners are motivated to operate their units to supply the demand.

3.2 Building Process Control, HVAC Control, Chilled Water Optimization

The building process control system monitors and controls the many components that provide heating and air conditioning such as chillers, fans, dampers, pumps, etc. These components may receive electric power or heat from the DER. The building heating needs that can be supplied from the DER take many forms. They could be heating of domestic hot water, heating for desiccant systems, or simply space heating. The DER must be controlled to optimize the heat available for these services, considering the other demands on the DER such as providing ancillary services, net emissions control, and the cost of fuel. Possibilities for thermal energy use are discussed further in Section 4.1.

There are a host of variables that must be optimized to obtain the most efficient operation of the many components of the HVAC system. The best setpoints for operation of the system will vary depending on the outside temperature and humidity, cost of fuel, sunlight angle and intensity, building occupancy level, and many other factors. The microgrid Energy Management System (EMS) will work in harmony with the conventional controllers (and control systems) for the individual chillers, boilers, heat pumps, heat exchangers, dampers, blowers, etc. and will not replace these control elements.

Many modern office buildings and industries are often equipped with energy management systems that optimize the operation of building heating and cooling equipment. The microgrid EMS would provide information to the existing energy management system and not replace the existing system. The existing HVAC control system would continue to monitor and control the water and airflows, temperatures, valve and damper positions, and motor operation. The microgrid EMS would, however, make the decisions as to the optimal mix of heat generation and electric power generation equipment.

At times of low natural gas cost, it may be more economical to use the boilers and furnaces to produce heat. During times of high electrical cost, it may be more economical to run the DER devices at maximum electrical power output and then use the waste heat in the building processes. This will be discussed more in Section 5.1. HVAC Process Optimization and Reliability.

Most importantly, it is important that the market for natural gas and the market for electricity send the correct signals to the microgrid EMS so that the microgrid, in responding to the market signals, will act like a "good citizen". A "good citizen" responds during periods of stress to help out, not to make things worse. For example, during times of electrical power shortages, the microgrid should find it profitable to maximize electric power production. Although this seems obvious, there have been market designs that induced the opposite behavior from the "good citizen" behavior. This is discussed further in Section 6, Significant Relationship with the Markets.

In many cases, there may be a trade off or compromise involved in operation of the DER and process systems. For example, operation of a heat recovery unit to provide heat for a liquid desiccant system will improve the efficiency of the building air conditioning, but on temperate days, the heat may be better used in some other application, or the DER may even be shut down for periodic maintenance. Making the correct decisions in these operational and system management scenarios requires an in depth understanding not only of the economics of system operation, but also requires input from the plant operator as to what the production schedule may be, input on the short term weather forecast, and input on market prices for fuel and power.

Finally, the energy management system must be capable of receiving status signals from the myriad equipment in the plant and in sending control signals for the proper operation of the equipment. For example, the control needs for a typical microturbine heat recovery system [2] are as follows:

- The EMS must make the decision when to use heat recovery, and must control operation of the system.
- When heat recovery is required, the DER exhaust is routed to the heat exchanger by controlling a damper, and water is routed to the heat exchanger by controlling a valve.
- The exhaust gas inlet temperature to the heat exchanger must be monitored so that the recovery system may be bypassed if the temperature is too low or too high. Typically, adjustable set points are used for this.
- The water temperature from the heat exchanger must be monitored to prevent overheating and also to provide a signal for the variable water flow control.

3.3 Energy Storage

The Microgrid Energy Management System will again only control the "dispatch" of the energy storage. The detailed operation of the storage systems, such as control of pumps, blowers, and flywheels will be managed by their own control systems. The Energy Management System will make decisions as to which energy storage devices to dispatch for various types of contingencies. Possibilities for thermal energy storage are discussed in more detail in Section 4.2.

In general, electric energy storage, using batteries, capacitors, or electro-mechanical storage methods such as flywheels, will only be used for voltage sags or actual electric outages, not to arbitrage hourly energy prices or to level out peak loads. Electric energy storage will be required to supplement the DER generators during low voltage transients on the distribution system or, when operating isolated from the distribution system, for motor starts or other short term overloads. The DER microturbines, fuel cells, and other small generators lack the "inertia" or ride through capability that large turbine generators have.

The electric energy storage devices will be truly key to the successful operation of the microgrid. The small DER sources, such as microturbines, are notorious for having so little inertia. For example, a 30 kW microturbine cannot start a 10 Hp motor unless some sort of storage is supplied. This is because the motor may draw 6 times normal current for several seconds as it is starting, and the microturbine has very little inertia. With a suitably sized energy storage device, such as a battery, and an inverter designed to handle six or seven times normal current for a short time, the motor could be started easily. Another common problem with DER, and not just the small inverter based DER but the larger synchronous machines, is the fact that they are not "stiff" voltage sources. This means that when a sudden increase in current draw occurs, the voltage can drop. This can actually happen five times per cycle with a non-linear load such as a diode rectifier. The resulting voltage waveform has five notches in each cycle, or a 300 Hz harmonic. In some cases the harmonic is so extreme that other equipment being powered from the DER will fail. Interestingly enough, common tests for harmonics often do not cover this effect. The DER is tested only with a nice stable load, and non-linear loads are not considered. Another common circumstance is riding through a momentary utility voltage sag. The energy storage device could be used to provide power during the sag to keep the voltage at the local bus essentially constant.

This storage will be connected to the DER inverters that condition the power output from the microturbines and other DER generators. In most cases, the voltage supplied from the storage will be DC, although in the case of the flywheel generators, it will be AC and connected directly to the 480V bus. Control of this electric energy storage cannot be the direct responsibility of the EMS. The EMS cannot be responsible for this fast acting response; operation of the storage will be fully automatic. The electrical storage devices will be required to discharge immediately in the event of a motor start or other sudden demand. The control system of the DER inverter will control the discharge and recharge of the electric energy storage devices.

Electric energy storage may take the form of simple batteries or ultra-capacitors, or it may be as complicated as Superconducting Magnetic Energy Storage (SMES). Some forms of energy storage, such as flywheels, are now integrated with generators. One flywheel manufacturer couples their flywheel with a backup reciprocating engine so that as the flywheel supplies power and gradually slows down, the engine may be started to power the generator. Some storage devices, such as capacitors, may have very high power density, but may only be suited for relatively short-term discharges. Other storage devices, such as flywheels coupled to written pole generators, may have lower power density, but may be capable of going to a deep discharge, and may be combined with a reciprocating engine to provide energy for extended periods.

3.4 Regulation and Load Shifting

Meeting the power demand for the microgrid is a challenge. Large-scale systems have the advantage of averaging power demand so that the load profile does not contain short-term peaks. Figure 3.1 is an example of this [4]. The peaks are the use of individual loads such as water heater, oven, heat pump, etc. in a home that sometimes are on at the same time. A small commercial establishment such as a restaurant could result in even more peaks. When many of these homes or restaurants are aggregated together, as in a large distribution system, the peaks have averaged out to provide the smoother curve that shows the load increasing during the day and peaking in the afternoon. This is represented by the gray curve in the background. With a microgrid composing a large industrial park or college campus, the load may be somewhat more like the averaged load shown in the figure. In general, the smaller the microgrid, the "peakier" its load will be, and the more energy storage will be required if it is to operate in stand alone or islanded mode. It is also possible that with energy storage, the gray curve could be averaged out and made flatter.

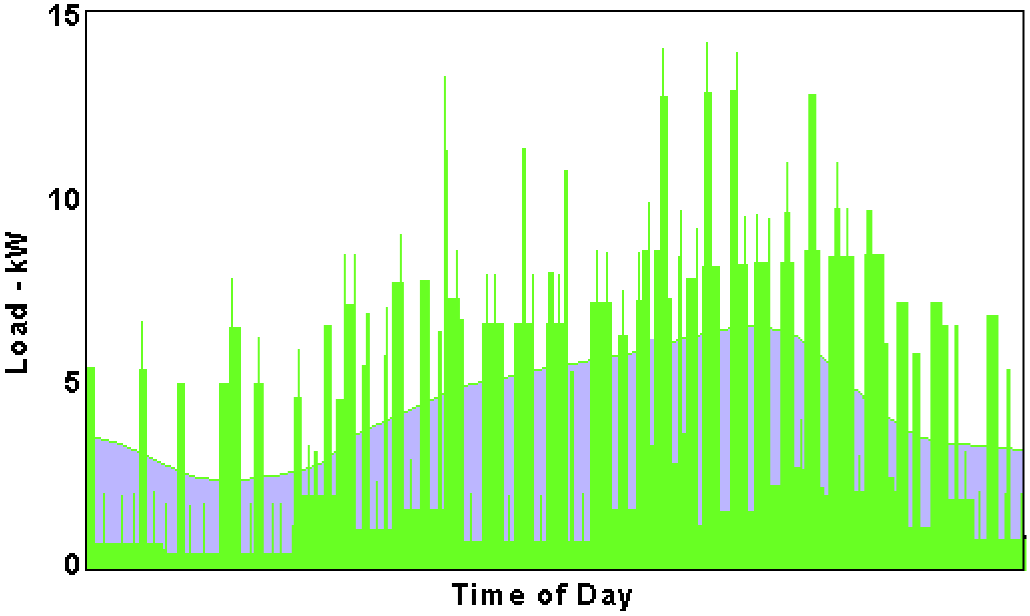

Figure 3.1 Average Power Demand

One of the valuable functions the Energy Management System can provide is to smooth out the electrical load profile. The Energy Management System can do this by starting loads whose start time may be somewhat discretionary at the specific times, which are more conducive to flattening the peaks. At least one utility company with large, volatile loads (steel mills) has developed a program to encourage the steel mills to coordinate the operation of their furnaces to reduce the peak demand. The EMS can also plan to "charge" thermal energy storage systems at night using low cost energy, and to actually help to flatten out the gray peak in Figure 3.1.

The service that utilities provide for adjusting generation to match load on a moment-to-moment basis is called regulation. If regulation is defined as a very short term service, say 10 seconds, then the amount required to follow time varying loads will be greater than if regulation is defined over a longer period (e.g. 2 minutes). [5] The remarkable problem is that when the microgrid is operating in the independent or grid isolated mode, essentially no time averaging can be tolerated, because there will no neighbors from which to draw power for short periods. All the second to second load demands will be met from the microgrid's own generation and energy storage. If adequate energy is not provided to meet changes in the load, the voltage will decay quickly or even collapse, a situation, which could not be tolerated.

Figure one [5] provides an example of generation following load for three utility systems. These figures were prepared using two-minute averages of data. It can be seen that there is not a perfect match of load and generation, although the load profiles are smoother in the large systems (the upper chart). In the larger system the generation does a better job of following the load profile. The load profile is much peakier in the lower chart; this for a 10,000 MW system, with data averaged over a two-minute period. The load following problem would be much worse on a 5 MW system with a need for essentially instantaneous response. Energy storage in the form of batteries, flywheels or ultracapacitors is required with a rapidly responding power electronics interface.

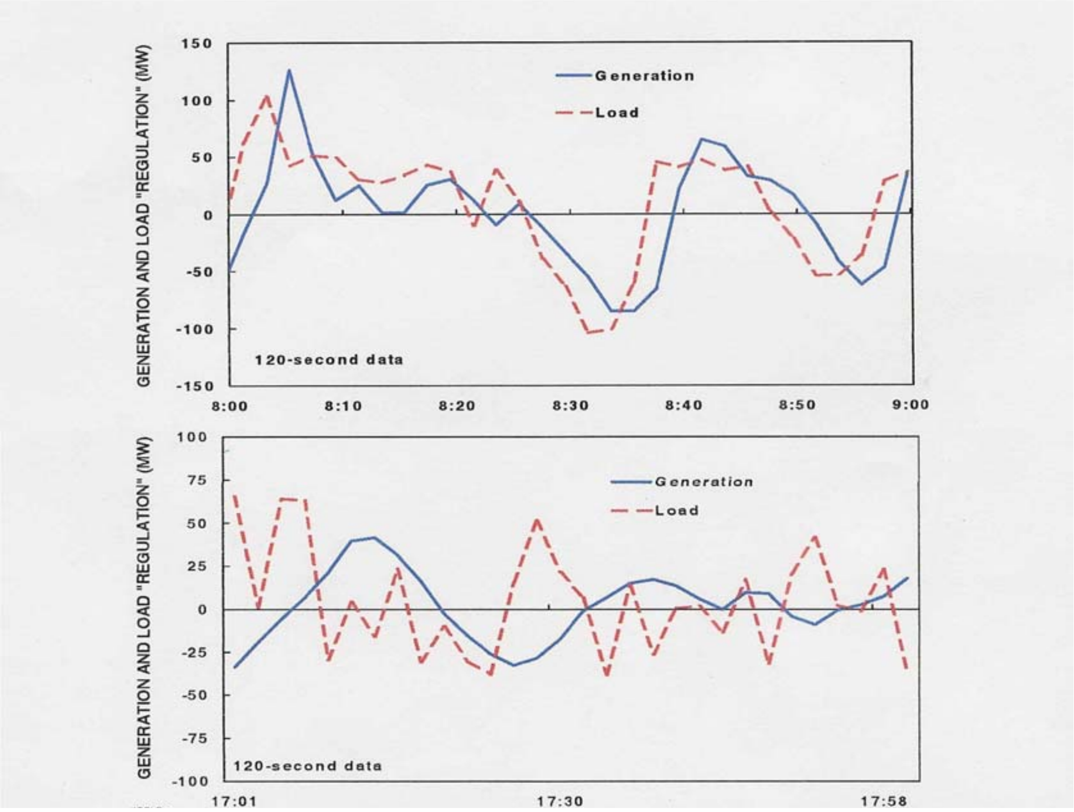

Figure 1

Regulation in Large (upper chart) and Small (lower chart) Systems

This serves as an illustration of the nature of the problem of regulation, it will be difficult for the generation and energy storage of the microgrid simply to follow every peak of the load profile. It will be essential to control the loads of the microgrid in a coordinated manner so that the peaks are minimized. This will apply to both heat and electrical power loads. To accomplish this control, the Energy Management System will need to have some intelligence of the microgrid's process, at least the large load elements of the process. The Energy Management System must be able to predict the turn on times of the large loads, and must be able to influence these times. The Energy Management System should also be aware of market conditions so that it can optimize energy use inside the microgrid and possibly supply services to the utility. The possibility of supplying services to the utility is discussed in the following section.

The topic of microgrids, equipped with energy storage, to supply regulation, is an interesting and exciting prospect. Microgrids which are designed to provide regulation could provide a valuable service. This topic is one which is listed as an area of future research.

3.5 Supply of Services to the Local Utility

There are diverse opinions on the subject of supplying services to the local utility. One school of thought holds that the microgrid is to act only as a controllable load. It can control the amount of load (kW) and the power factor, but it will never supply power to the distribution system. Another school of thought is that the microgrid can supply power to the distribution system and could sell this power through the power market. In fact, the microgrid can supply many valuable reliability services to the grid while acting only as a controllable load. In the new, developing market systems, the microgrid could be paid for supplying these services. A thorough discussion of the range of ancillary services that could be supplied is provided in Section 7, Significant Relationship with the Distribution System.

The philosophy of a microgrid as a controllable load is particularly palatable to utilities, as their transmission and distribution systems are designed and engineered to supply power to loads, and not to have two-way power flow in distribution systems. Another aspect of this philosophy is that even without supplying power to the utility, the microgrid can still supply significant services to the utility. The ability to control load is extremely important to a utility during times of system stress. Reducing 5 Mw of load in an overloaded feeder can do more to restore local voltage than supplying 10 Mw of generation at a distant generator. The ability to control load enables a powerful control of voltage. Also, the ability to control power factor enables voltage control. A power electronics interface will enable a microgrid to draw even a leading power factor, thus allowing another form of voltage control. Connecting capacitors in distribution systems has long been a method of providing voltage control. Microgrids could control power factor automatically in response to a sensed voltage and a voltage schedule, or desired voltage signal from a central controller.

This school of thought, that the microgrid is purely a controllable load and never exports power, is actually a sound engineering position and has tremendous value. When the microgrid is used to rapidly control load, it is in a sense providing many of the traditional ancillary services that utilities require. A brief discussion of ancillary services is provided below. Ancillary Services are covered in more detail in Section 7, along with a discussion of how they could be provided by a microgrid.

Key Ancillary Services and Their Definitions:

Reactive Supply and Voltage Control from Generation: Injection and absorption of reactive power from generators to control transmission voltages
Regulation: Maintenance of the minute-to-minute generation/load balance to meet NERC's Control Performance Standard 1 and 2
Load Following: Maintenance of the hour-to-hour generation/load balance
Frequency Responsive Spinning Reserve: Immediate (10-second) response to contingencies and frequency deviations
Supplemental Reserve: Response to restore generation/load balance within 10 minutes of an operator's command
Backup Supply: Customer plan to restore system contingency reserves within 30 minutes if the customer's primary supply is disabled
Network Stability: Use of fast-response equipment to maintain a secure transmission system
System Blackstart: The capability to start generation and restore all or a major portion of the power system to service without support from outside after a total system collapse

The five remaining services (Regulation, Load Following, Frequency Responsive Spinning Reserve, Supplemental Reserve, and Backup Supply) deal with maintaining or restoring the real-energy balance between generators and loads. Microgrids will be able to supply all of these services except blackstart without delivering power out to the distribution system, but only by controlling their load. The blackstart service is usually a highly specialized service that the utility uses certain specially prepared generating stations to perform. Ancillary Services are covered in more detail in Section 7.1 with a discussion of how they could be provided by a microgrid.

One of the biggest challenges for the provision of ancillary services will be communication speed. Since fast services generally command higher prices than slower services, it is desirable to sell the fastest service possible.

FERC is encouraging open competitive markets for generation, both energy and ancillary services. FERC ordered the unbundling of ancillary services from transmission to promote competitive markets, which should improve economic efficiency and lower electricity prices. Beyond the argument of fairness, having microgrids participate as suppliers, as well as consumers, of electricity services improves resource utilization. Ancillary services consume generating capacity. When microgrids provide these reserves, central generating capacity is freed up to generate electricity.

Section 4. THERMAL ENERGY UTILIZATION

This section of the report discusses some of the possibilities for utilization of the heat generated by the various microsources. Residual heat from generation is used extensively in many large industries now in Combined Heat and Power applications. The operating efficiency of the microgrid can also be increased significantly with the utilization of the "waste heat". This section provides a description of some of the components that can make use of the heat such as absorption chillers and desiccant dehumidifiers. There is also a discussion on the need and possibilities for thermal energy storage.

4.1. Microsource Supply of Thermal Energy to HVAC and Operations (CHP)

A key consideration in the use of "waste" heat from the microsource is one of efficiency. In the traditional energy source of central, fossil fuel powered generation stations, at least 50 to 70% of the energy content of the fuel is lost at the power plant alone through energy conversion efficiencies, and is discharged as waste heat into the environment. Further losses, about 8%, occur in the electric power transmission and distribution network. [6] If the fuel were consumed at the user's load - an industry, office park or campus, the waste heat from the power generation could be used instead of being discharged. This would boost overall efficiency and reduce emissions.

Clearly one of the most effective ways of getting the greatest cost savings from traditional microgrid systems is making use of the thermal energy byproduct. The thermal energy produced by reciprocating engines, gas turbines, microturbines, fuel cells, stirling engines, etc., can all be used for the following thermally activated technologies:

- Facility/room air heaters
- Heat Recovery Steam Generators
- Heat recovery boilers
- Desiccant dehumidifiers
- Steam turbines
- Absorption chillers
- Hydronic reheat coils
- Hot water heaters
- Humidifiers
- Thermal energy storage systems

The use of combined cooling, heating and power (CHP) can provide a 30% improvement over conventional power plant efficiency and result in a total system efficiency of 80% through the use of thermal energy that would otherwise have been wasted. Any additional thermal energy contributions to industrial and commercial (I&C) processes would only improve cost savings further.

The United States Combined Heating and Power Association (USCHPA) [13] states that 8% of U. S. electric power is produced by CHP systems with the following benefits:

- Saves building and industry owners over $5 billion each year in energy costs
- Decreases energy use by almost 1.3 trillion BTUs per year
- Reduces NOx and SO2 emissions by 0.4 and over 0.9 million tons/yr, respectively
- Prevents release of over 35 million metric tons of carbon equivalent

About 56 GW of CHP generation are in operation in the U.S., up from less than 10 GW in 1980. [7] The majority of this is boiler systems with steam turbines. Waste heat from CHP is used in the chemical, petroleum refining, paper, food, and pharmaceutical industries, as well as on university campuses. The large industrial systems with an electrical capacity of over 50 MW electric are often merchant power plants using combined cycle configurations. They may be owned by an independent power producer that has an industrial customer for the steam.

District energy systems (DES) are a growing market for CHP. [8] DES distribute steam, hot water, and/or chilled water from a central plant to individual buildings through a network of pipes. DES provide space heating, air conditioning, domestic hot water, and/or industrial process energy. DES expand the number of thermal loads that can be served by CHP. DES are installed at large campuses such as universities, hospitals or office parks.

The type of CHP we are primarily interested in for this report is that using reciprocating engines, combustion turbines and microturbines. Several manufacturers now have packaged systems starting as small as 25 to 30 kW. This market is just starting to develop. The efficient use of the waste heat from these small systems will be somewhat more challenging than the use of steam from the baseload 50 MW combined cycle plants. The large plants were designed to provide the steam for a large, established load, such as heating of dormitories, heating petroleum in a refining operation, or cooking in a food processing industry. The steam loads were essentially designed at the same time the boiler was sized, and the electric power production is basically a side benefit.

In microgrid applications, the same principle applies. The heat loads ideally should be designed into the system at the time of project conception. The heat loads may be domestic hot water, or heat-activated air conditioners, chillers and desiccant dehumidifiers. These devices are typically costly to back fit into an existing building. In addition, most are relatively new technologies. Most importantly, for the EMS system, their operation must be coordinated with the operation of the microsources. This may be the most difficult aspect of their use. The most attractive time to operate the microsource will undoubtedly be during on peak hours. This may or may not be the times when the heat loads are required. An alternative is to use thermal storage if the electric and thermal load requirements are not coincidental.

A modular or packaged CHP system may be a key to successful integration of CHP in small scale, microgrid applications. For example, the packaged systems may contain a microturbine packaged with a desiccant type dehumidifier and absorption chiller. The microturbine would generate power for the building, and the waste heat in the exhaust would power the absorption chiller and dehumidifier. The advantage of using DER in air conditioning applications is that the peak demand for the air conditioning typically coincides with the utility peak demand for power. A test of such a system is being performed at the University of Maryland for the Department of Energy. [9]

Figure 4.1 illustrates how electricity and heat can be generated separately (i.e., traditionally) or locally in one or more CHP generators. The figure, adapted from a presentation by the USCHPA [14], shows that the same amount of electricity and heat generation can be accomplished starting with 180 units of fuel energy using the traditional approach or with only 100 units of fuel energy using CHP. Of key importance is the loss of 79 units of energy from the centralized power plant. Grid losses and boiler losses tend to offset the CHP generator losses (assuming, in this case, that a microturbine is used).

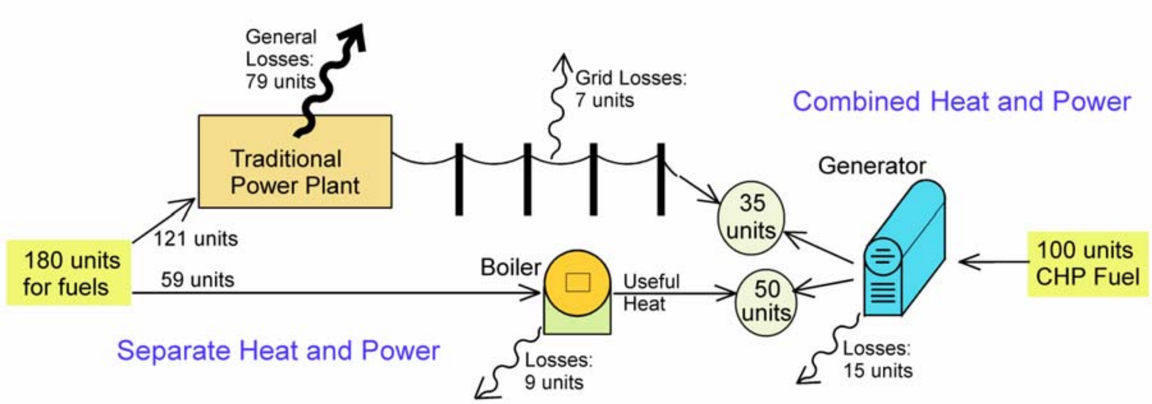

Figure 4.1 Overall efficiency of CHP vs. separate heat and power generation [ref]

4.1.1 *Absorption Chillers*

The absorption chiller uses a condenser and evaporator just like a conventional vapor compression system, but it replaces the motor driven compressor with a thermal compressor. The thermal compressor (consisting of an absorber, generator and small solution pump) takes in low-pressure refrigerant (suction) and creates high-pressure refrigerant (discharge). The high-pressure refrigerant vapor (typically water or ammonia) passes from the thermal compressor component called the generator to the condenser. This water vapor is condensed to a liquid and the heat of condensation is rejected to the ambient air. The liquid refrigerant now passes through an expansion valve that reduces its pressure, and thus reduces its boiling temperature. The low-pressure refrigerant then moves into the evaporator, where the liquid boils by drawing heat from the chilled water stream flowing through the evaporator, thus cooling the chilled water. Next, the low-pressure refrigerant vapor passes from the evaporator into the thermal compressor component called the absorber. A strong absorbent solution (typically lithium bromide/water solution or ammonia/water solution) that has a relatively strong affinity for refrigerant is also added to the absorber. In this way, the low-pressure refrigerant vapor is pulled into solution that is called the absorption process. After the low-pressure refrigerant vapor and the strong absorbent solution combine to give the weak absorbent solution, this solution is then sent through a solution pump to the generator where heat is added to boil the refrigerant from solution. The strong solution is sent back to the absorber after its pressure is reduced through an expansion valve and the high-pressure refrigerant vapor then passes to the condenser to repeat the process. To improve efficiency of the chiller, a solution heat exchanger is usually placed between the weak absorbent solution stream entering the generator and the strong absorbent solution stream leaving the generator. This internal heat recovery reduces the required heat input to boil the refrigerant out of solution, thus increasing the efficiency of the chiller.

4.1.2 *Desiccant Dehumidifiers*

Desiccant dehumidifiers consist of a desiccant wheel filled with desiccant material and a process and regeneration air circuits. As the process air flows through the desiccant wheel, the moisture is removed from the air stream that would be entering the building. The desiccant material is restored to its dry state by exposure to the heated regeneration air stream as the desiccant wheel rotates. The regeneration air is then discharged to the atmosphere. When the desiccant removes moisture from the air, heat is released and the air is warmed. Heat recovery devices are then used to cool the air, and a conventional air conditioner is used for the final cooling. The final cooling requires much less energy because the air is dry and moisture does not have to be condensed and cooled. In some desiccant systems, a wheel containing desiccant material continuously dries the air and then passes through the waste heat stream where the moisture is driven out.

4.2 Microsource Relationship to Thermal Energy Storage

Thermal Energy Storage (TES) may be used to store energy for HVAC or process needs. TES is a peak shifting technique that uses many different storage mediums such as chilled water, ice, eutectic salt or even concrete or stone. One conventional method is to use HVAC chillers with a thermal energy storage tank to shift peak loads. [3]

When generation shortages or hot weather are predicted for the next day, the EMS may choose to have utility or onsite power used at night to "charge" a thermal energy storage tank. During on peak times, chilled fluid may be circulated from the storage tank through a secondary heat exchanger to supply on peak cooling. There are three basic storage-sizing strategies: Full Storage, Demand Limited Partial Storage, and Load-Leveling Partial Storage. Full storage can shift all HVAC demand caused by cooling to off peak hours. Demand limited partial storage lowers the peak demand to predetermined level, which is normally equal to the demand, imposed by the non-cooling loads. This method requires real time control. Partial storage supplies only part of the cooling needs and helps to level demand. [3] The Energy Management System will be able to dispatch the TES based on the next day's cost of power and weather forecast, and then to control it during the on peak period.

5. PROCESS OPTIMIZATION AND RELIABILITY

This section discusses the functions the microgrid and EMS can provide in optimizing the operation of the HVAC and other process systems. Section 5.1 describes the possible role of the EMS in system optimization. Section 5.2 discusses power quality and power cost considerations.

5.1. HVAC Process System Optimization and Reliability

One of the most important functions of the EMS is to optimize the efficiency of the HVAC system. The analysis required to do this optimization is not trivial. Each of the key components of the HVAC system has its own energy efficiency value. These include the efficiency of the chillers, the pumping system, the evaporators, cooling towers, etc. The efficiency parameters are often expressed as the Coefficient of Performance, or COP. The COP is the ratio of the heat (or power) output to the power (or equivalent fuel value) input. The COP will vary depending on a variety of factors, such as load, humidity, etc. In [10], the COP of various processes in the HVAC system are reported as follows:

- Purchased Natural gas is converted to useful heat at an efficiency of 0.85.
- Residual heat is converted to useful heat at an efficiency of 0.7.
- Electric generation efficiency for a reciprocating engine from the input fuel to the delivered kWh is 0.28.
- Absorption chillers can reduce electrical cooling load with an efficiency of 1.0.
- Electric, compressor driven air conditioning systems have a COP of 5.0.

The economic analysis of the microgrid uses these coefficients to assess the cost of various combinations of DG, CHP and absorption chiller technologies. As an added complication, the COPs of many components is strongly dependent on ambient temperature. For example, a heat pump may have a COP of 5 when the outside temperature is 45 degrees, but it may go down to 0.3 or less when the outside temperature goes down to 15.

In addition, HVAC equipment is notorious for contributing to the peak load. To shift load, thermal storage is readily adaptable to commercial cooling systems and their central chilled water plants. However, the operation of the thermal storage system depends on many factors such as the type of storage, the climate, weather forecast, operating temperature, etc. The optimal use of storage will require long term contract arrangements and planning for DER operation to provide heat for absorption chillers, desiccant dehumidifiers, domestic hot water, etc. Because of the number of considerations involved, there really will be no other method to manage optimization other than with an EMS.

In [10], the entire microgrid, consisting of a shopping center, was analyzed as one customer. Overall cost savings of 65% were achieved by using a combination of DER and CHP. It was interesting that because the electrical load in the shopping center was

10 times larger than the thermal load, the residual heat from the electricity generation was not all used productively. It was found that if the thermal and electrical loads were matched exactly to the output of the CHP system, the system overall energy efficiency would be 93%. The authors pointed out that "The model assumed that all waste heat was of the same type and quality. However, in a real CHP system, the specific type and capacity of the thermal end-use, temperatures, flow rates, distances, pressures, efficiency curves, become important." The EMS system would have access to all this information, updated in real time, and could optimize the operation of the HVAC system and the DER to achieve maximum overall energy efficiencies.

In [11], it is noted that building HVAC systems rarely perform as well as had been anticipated during the design. It was reported that half of a surveyed set of buildings were experiencing control problems and that 25% had energy management systems that were not functioning properly. One reason for this is that energy management systems are becoming more complex over time and are difficult for operators to understand. The report describes an Information Monitoring and Diagnostic System (IMDS) that was installed at the test building with data visualization software, 57 measured points and 28 calculated points. Only after several months of careful examination of the trended data did the operations staff began to understand how the original controls and systems actually functioned. The IMDS identified operational problems, significant savings opportunities, and has been used to improve the use of the existing controls. Data visualization software is truly essential to understanding the operation of complex systems, and it will become much more important to economically optimize the operation of microgrids operating in concert with utility distribution systems and building HVAC systems.

More advanced control strategies also hold the potential for greatly improved overall efficiencies of the HVAC system, and the resultant improvements in air quality. In [12], there is an extensive discussion of indoor air quality. Air quality refers not just to the temperature of the air, but also the humidity and CO2 level. Conventional thinking is that improved air quality translates directly to higher electric costs for operating HVAC because the air has to be cooled first to control the humidity and that more air changes per hour are needed to control CO2 when there are a large number of people in the building. The report provides a study of a large building on a college campus, and finds that by actually monitoring the CO2 level and controlling based on the air temperature, humidity and CO2, that the HVAC energy costs could be cut by 53%. This represents a 34% reduction in total building electric energy costs. The CO2 level was kept at a level of 700 to 1,000 ppm during the study, which is an acceptable level. It was found that large rooms like auditoriums, needed much less outside air when there were very few people in the room. This sort of control is not readily provided by conventional HVAC control methods, but the type of information monitoring and diagnostic system discussed above could easily be capable of the providing the needed algorithms.

In one study [15], a form of EMS was used to model the Engineering Tower Building (ETB) at the University of Pretoria. This was a verification study to verify the “real world” dynamic interactions between the building model and the HVAC system models with influence of controllers in an integrated fashion. First, a comfort and energy audit was conducted where measurements of indoor air conditions were made to determine whether standards were being met and to verify the simulation model. In addition to a walk through audit, occupant's opinions were obtained regarding air quality in the lecture halls. The study proceeded to determine the end-user breakdown of energy consumption in the ETB to identify the largest energy consumers. It was discovered that the HVAC consumed about 64% of the building energy.

Year long simulations were executed to calculate the potential for annual energy savings. Advantage was taken of certain lecture halls that were not occupied for portions of days and portions of the year. The study also looked at an air economizer combined with carbon dioxide control. The integrated simulation tool predicted savings up to 491,000 kWh per year and a 9-month payback using simulations of certain control retrofit options. Other options with even a shorter payback were identified. Without the aid of the simulation tool, it would not have been possible to evaluate the energy savings while still ensuring acceptable indoor comfort.

5.2 Manufacturing Process Optimization and Reliability

5.2.1 *Power Quality*

Today's electronic loads are susceptible to transients, sags, harmonics, momentary interruptions, and other disturbances that historically were not cause for concern. The *quality* of electric service has become as important as its *reliability*. Power quality is a new phenomenon. Events that used to be ignored, such voltage sags that last only one or two cycles, are now classified as outages. Events such as momentary interruptions, harmonics, and phase imbalance are now power quality concerns. Power quality problems have a huge economic impact.

Defining the exact cost of power quality problems is difficult because there are so many industrial applications and so many power quality measurements. The attributes of power quality problems are:

- Magnitude – How great is the excursion? Costs can vary from process interruption to equipment damage due to high voltage excursions.
- Duration – How long does the excursion last?
- Frequency – How often do the excursions occur?
- Timing – What time of day do the events take place?
- Predictability – What advance notice, if any, does the customer have?

A recent study [19] prepared by the Lawrence Berkeley National Laboratory discusses the above attributes and the impact on susceptible office/manufacturing equipment. This study found estimates of U.S. outage costs ranging from $25 billion per year to $150 billion per year.

Power quality may be controlled locally in the microgrid in response to the user's needs. Power quality may even be controlled on an hourly basis. Addressing a particular user's special power quality needs is difficult for the transmission and distribution system. The transmission and distribution (T&D) system is inherently a communal asset, and, as such, provides the same level, or quality, of service to all customers within a given area. The T&D system does not easily differentiate among different customers' needs.

There is interest, in some locations, in improving overall power quality. In Victoria, Australia, a special rate structure is being developed to reward utilities that provide higher levels of power quality. [16] This rate structure provides an incentive to the utility to avoid outages. These incentive rates are rather unforgiving when it comes to system contingencies. In fact, regulators in Victoria specifically mentioned severe storms, load shedding, and shortfalls in generating capacity as external events for which the distribution company should remain liable. The regulators' thinking is that the distribution utility is in a better position to take action to mitigate the risk than individual customers are. This may sometimes be true; however, the customer who operates a microgrid is in a tremendous position to enjoy exactly the power quality level he requires, and without paying any tariff or fee for the improved quality.

Because the T&D system is a communal asset that tends to provide the same level of service to all customers within a given area, having the T&D system address individual increased reliability and power quality problems could be problematic. The problem centers on the fact that the regulated entity may shift costs from the customers for which it is competing, to other customers that are captive to its monopoly services. How could this happen? A T&D utility that wants to sell premium power to an industrial customer could, for example, design $100,000 of improvements to the distribution system and claim that $60,000 of them are really supporting the system as a whole and should be placed in the regulated rate base. It would then offer the premium power solution to the industrial customer for $40,000. It can be very difficult for someone on the outside, or even in some cases for a regulator, to know if this split between the regulated ($60,000) portion and the competitive ($40,000) portion is appropriate.

A strong case can be made that it is often best for the customer, using solutions such as a microgrid, to provide his own needed level of power quality.

5.2.2 *Power Cost Considerations*

This section briefly discusses the high national costs resulting from transmission congestion (which energy customers ultimately pay for) and then considers how microgrids can help not only on a national scale but most certainly on the local user scale for reducing power costs. This section discusses a few localized technology solutions (e.g., improved controls) that are well suited as applications for microgrid systems. One such solution, *Cybernetic Building Solutions*, which holds promise for the future is presented in a text box at the end of the section.

Costs of Transmission Congestion

The very presence of a set of functioning microgrids, whether optimized for efficiency or not, provides some level of value to the nation's periodically over-stressed transmission system. Interregional transmission congestion cost consumers hundreds of millions of dollars each year. These costs do not include the high cost of the resulting power interruptions to thousands of industries where energy reliability is critical.

Relieving bottlenecks in just California, PJM, New York, and New England could save consumers about $500 million annually [17]. This cost, high as it is, does not include transmission bottlenecks that exist in sub-regions. As an example, ISO New England believes that the cost of congestion in New England is between $125 million and $600 million each year [18].

In addition to the *present* cost of congestion, DOE reports that, according to NERC, investment in new transmission facilities is lagging far behind investment in new generation and the growth in electrical consumption. Thus, there is a reasonable expectation that congestion may worsen. Microgrids, and distributed generation in general, are important means for reducing peak loads. When aggregated together, microgrids could have a significant impact on congestion.

Basic Microgrid Cost Considerations

The follow is a list of benefits (i.e., mostly monetary) that can be realized through the use of microgrid power generation:

- *Lower generation cost* depending on generator efficiency and local power costs (including demand charges). This is the first and most obvious consideration that is always carefully quantified based on various projected future fuel costs (i.e., natural gas) and projected electricity costs. However, some level of financial uncertainly and risk will always exists.

- *Generation efficiency* can be greatly improved by using the fuel (e.g., natural gas) to provide electrical power <u>and</u> heat, which would otherwise be wasted (see next section on Combined Power and Heat).

- *Power exporting* may be feasible depending on tariffs and local standards for interconnection. Exporting power can result in a high cost benefit at some locations during times of high power congestion on the local grid. This prospect may increase in years to come as the nation's transmission system becomes even more over-taxed.

- *Improved power quality,* facilitated by generation that is distributed, can provide very high availability and reliability that will save large sums of money for certain industries and businesses. The high availability is possible not only from generation redundancy but also from operating independently from the grid, which causes most disruptions.

- *Line losses* account for 5% to as much as 20% (during peak demand) of conventional power that is lost to transmission resistance. Optimally placed CHP systems can significantly reduce line losses even within an industrial plant and reduce the need for installing/upgrading feeders between microgrid locations.

- *Environmental air quality* improvements are possible due to improved technology (e.g., microturbines) and the use of renewable energy sources (e.g., wind and solar) that are often favored for use at commercial buildings. These advantages may translate to savings if local tariffs, incentives, or statutes allow the user to obtain emission reduction credits for displacing, reducing, or eliminating emissions from grid-generated power.

- *Fast expansion* is possible because of the short lead times for using off-the-shelf commercial generation products. Not only does the user benefit from rapid, efficient responses to demand growth; but also, some portions of the microgrid can be powered down temporarily in response to market fluctuations. The financial benefit may be difficult to quantify but, for some industries and/or circumstances, it can be substantial.

Finally, the following is a concept of an interactive EMS system with an estimate of the cost savings.

Cybernetic Building Systems (future concept)

The control of Microgrid systems can be included in cost-effective, multi-building interoperability systems called cybernetic building systems (CBSs). In the CBS, multi-system configuration is communicated and controlled simultaneously at multiple levels. The system may include,

- Energy management (e.g., HVAC, lighting)
- Life safety (e.g., fire detection and protection)
- Building security (i.e., access control)
- Fault detection and diagnostics
- Optimal system Control
- Real-time purchasing of electricity

The CBS approach is somewhat conceptual at present and work must be done such as addressing how the systems will communicate, interact, and share information throughout the industry or within the U.S. domestic market. Perhaps the most immediate need is demonstrating the net economic savings that is possible from using CBS products and services. In one study [36], the cost and savings estimates were looked at by first specifying a base case (i.e., traditional approach) and a CBS alternative. As expected, in the CBS alternative, the degree to which building service features are integrated, automated, and controlled is much higher, creating a potential for enhanced service. The value of the annual cost savings in energy in 1997 dollars per square foot was found to be $0.16. There were also associated savings in lower maintenance costs and increased occupant productivity.

The study used several types of information in generating estimates of cost savings:

- Diffusion models
- Per unit cost savings for energy, maintenance, repairs and replacements
- Per unit cost savings for occupant productivity
- Additional costs to building owners and managers for installing CBS products/services

This modeling, which covered a period of years from 2003 through 2015, showed an adjusted internal rate of return of about 20% per year over the 13-year period.

6. SIGNIFICANT RELATIONSHIP WITH THE MARKETS

For the microgrid concept to become widespread across the nation there must be a strong financial incentive for the owner and for the utilities. These financial incentives will not exist until there is a market for the services the microgrid can provide to the distribution system. The development of such a market will take major institutional changes, but the reforms are occurring already in some parts of the nation. Services such as voltage regulation are being considered in trial programs in some areas. This section discusses some of the possibilities in the electricity market, the weaknesses in the natural gas market, and the reforms that are needed. After the market reforms are made, the range of valuable services described in section 7 would become a reality.

6.1. Electricity Market - Possibilities in Various Market Systems

The power system of the future will fully integrate DER into energy and ancillary service markets. Prices for energy and the ancillary services would change hourly (or faster) to reflect current system conditions. As the system became stressed, prices would rise. Broadcasting prices would allow all resources to respond and mitigate reliability concerns. Price would be the dominant means of achieving desired response, not command and control signals.

Microgrids that could not respond to price signals, due to their own economic or physical constraints, would continue operating as their own internal requirements dictated. For those that do not respond, commercial financial instruments such as hedging contracts would replace the provision of services as a shield from the volatility of markets. Those that could respond would receive the economic benefit. Aggregators and marketers would help both the system operator and individual generators by bringing together resources with complementary capabilities. Automated decision tools would likely handle interactions with energy and ancillary service markets so that the EMS could be easily programmed to respond to price signals.

By watching the market for some time, each participant could decide if investing in additional flexibility would be profitable for them. Flexibility could be gained by adding generation, controlling more load, or adding forms of storage. This process allows markets to optimize the power system and the individual participant's businesses while minimizing central planning and control.

Software tools are presently available that perform detailed economic assessments. Some help DER owners determine hourly deployment schedules based on rates or wholesale spot market prices. Some companies, such as Sixth Dimension, Engage Networks and Silicon Energy have products that use real time price data to automatically make hourly deployment decisions. [20] A discussion of the real time analysis tools presently available in DER control systems was provided in Section 1.

Some of the existing financial analysis programs are quite detailed in their modeling. Some of the considerations that are modeled include:

- Turbine performance under site-specific conditions.
- Daily demand for energy and thermal load in blocks of time.
- A weather database used for predicting demand.
- Dual fuel configurations with natural gas and number 2 fuel oil.
- Evaluation of NOx, ammonia, and CO emissions including the cost of needed controls.
- The cost of standby charges.
- Thermal utilization.
- Avoided demand charges.
- Avoided thermal energy price.
- Avoided emissions.

6.2 Gas Market

The nation's currently projected electric load growth brings considerable pressure on the nation's natural gas delivery system. New electric generation, predominantly gas fired, is expected to raise natural gas demand by as much as 20 billion cubic feet per day (BCF), more than a 30% increase over existing deliveries. [21] Several important consequences may result from this dramatic increase. The price of natural gas will be elevated to a new, higher level, second, increased pressure is being placed on gas pipeline capacity. In New England, which is now enjoying the addition of more than 10,000 MW of new capacity, 77% of the region's pipeline capacity may be consumed for power generation, and the potential loss of compression from pipeline interruption or compressor failure on the region's pipelines will soon become the largest single contingency that reliability planners must face. A pipeline failure can cause a greater loss of generation than a failure of New England's largest nuclear power plant.

In the event of a shortage of natural gas, the competitive market can potentially have a deleterious effect on reliability. When a supplier or class of suppliers (gas fired generation) is unable to supply power to the grid, the customer load will not simply be cut off, the "orphaned" customers will become the electrical security responsibility problem of the system operator. A problem with a specific class of generation can become everyone's reliability problem. This was a reality demonstrated repeatedly during the rolling blackouts in California in 2000 and 2001. [21]

Another interesting factor is that for a vertically integrated utility, a reduction in sales is always accompanied by a comparable reduction in power cost. However, for a distribution - only utility (a wires company) there is no accompanying reduction in operating costs for a reduction in sales. In addition, a wires company has a relatively small equity rate base. For this reason, a 5% reduction in sales can actually result in a 50% drop in return on equity. [21] This may explain why for some distribution - only utilities the prospect of 20% or greater penetration of DER may appear threatening under today's market designs.

6.3. Possible Market Reforms

Variations in supply side costs are presently not reflected in retail price signals. The retail customer sees the same cost regardless of what is happening on the utility side. The cost information needed to stimulate demand side responsiveness is not available unless the EMS participates in the wholesale power market. The market situation is complicated, and beyond the scope of this report, but it may be summarized as follows. There are six reasons that the EMS may not be able to properly respond to market conditions: [21]

1. Real wholesale costs may not be reflected in the retail tariff. Otherwise, microgrids could be extremely price sensitive to both electricity and natural gas costs, and could be tremendously responsive.
2. Wholesale energy markets do not have a built in demand side (i.e. responsiveness from the microgrid.) Microgrids, equipped with Energy Management Systems, could provide a highly elastic demand curve. This would be of significant value in a day ahead market, where the EMS could bid in "capacity" based on the weather and process plans for the next day. This would permit one day to plan consumption and generation.
3. Load profiles used to assign wholesale costs to load serving entities fail to account for the actual costs of service. A level profile has a significantly lower actual cost.
4. Demand side resources are effectively excluded from the wholesale markets for reliability services. The ancillary service markets should be opened so that microgrids could bid in.
5. Transmission constraints have not been recognized in the pricing of wholesale energy services. Locational pricing reveals the value of distributed resources in alleviating congestion across constrained interfaces.
6. The markets for reactive load management, voltage regulation, and other demand side services are immature, if they exist at all, and will remain uncertain until equitable market rules are established. There is a need to reform price caps and default service rates to reveal the value of load profile response at different times and locations and to create markets for ancillary services to the distribution utility. Possibilities for ancillary services are discussed in section 7.1 below.

Most importantly, investments in load management are not only beneficial to those consumers who use the technologies, they also lower the wholesale market prices paid by all consumers. [21] The Massachusetts Department of Energy Resources concluded that the measures installed in their post-restructuring efficiency program lowered the participants' electricity cost by $20 million in 1999. The Department also concluded that, by lowering peak demand at high cost periods, the programs provided reliability and power cost savings to all customers, participants and non-participants alike. The benefit in just 13 hours on one high-cost day exceeded $6 million due to the effect on the wholesale energy-clearing price.

7. SIGNIFICANT RELATIONSHIP WITH THE DISTRIBUTION SYSTEM

One of the most exciting prospects of the microgrid controlled by the EMS will be its ability to provide Ancillary Services, or reliability services. As discussed above, the market changes must come first, but the microgrid is in a much better position to provide services than conventional generating stations. Conventional generating stations are often located far from load pockets, such as urban areas, and it is difficult to impact problems occurring in the load pockets during times of system stress. Microgrids located near urban centers could provide these services much more efficiently. This section describes the range of services that could be supplied and discusses the technical and institutional barriers that must be overcome.

7.1. Supply of Ancillary Services

Electricity is a unique commodity in that production and consumption must be matched essentially instantaneously. Storage is not practical. Use of alternating current, while it provides the tremendous benefit of relatively cheap voltage transformation, further restricts operational options. Flow cannot be easily controlled on individual transmission lines so control of the system to prevent overloads must be accomplished by redispatching generation. Consequently, the production cost of electric power is highly volatile. In spite of this, historically we have elected to isolate the consumer from the power system's real-time production cost. The vertically integrated utility typically owns all of the generation, controls the system, and owns and operates the transmission and distribution network. Consumers use power whenever they choose and the power system responds to accommodate those needs. The customer does not see prices that reflect current conditions and cannot benefit financially if it takes action to help the power system. Consumers pay the higher cost incurred by the system to isolate them from real-time fluctuations through higher average prices. Worse, all consumers pay even if the higher costs result from the actions of a few.

Historically, there has been little interaction between energy customers and the electric power system that supplies them. Electric utilities viewed users as largely unwilling or unable to modify electric power consumption. Users received few economic signals to guide their energy use. Seasonal rates, time-of-use tariffs, demand charges and interruptible rates are the limit to most interactions. Restructuring of the electric power industry offers the promise of a much richer set of interactions.

While most restructuring activity to date is occurring on the supply side, this situation is changing. Ancillary services, or reliability services as they are sometimes called, are simply the supply of real or reactive power when it is needed. This power is held in reserve to be used in situations where the grid is under stress. These reserves can be supplied by either generators or loads, so the traditional distinction between supply/generation and consumption/load is breaking down. Market participants can be both suppliers and consumers of different services at different times.

Microgrids could prosper by recognizing that the prices of electric energy and the reliability services (ancillary services) vary dramatically in time. These price changes are only somewhat predictable. Prices will generally be higher on hot August afternoons than they are after midnight on spring mornings. But times of extremely high prices, like the $7000/MWH and $9000/MWH prices seen in the mid west over recent summers, are less predictable. Microgrids could benefit by curtailing consumption, by selling energy to the power system (if they have on-site generation), or by selling reserves to the power system during times of high price.

From the power system's point of view, there are several reasons that microgrids and operators (and all distributed generators and loads) should be encouraged to sell ancillary services. FERC is encouraging open competitive markets for generation. FERC ordered the unbundling of ancillary services to promote competitive markets, which should improve economic efficiency and lower electricity prices. These markets should be open to any technology capable of providing the service, not just central generators. This will expand supplies and reduce horizontal-market-power problems.

Beyond the argument of fairness, having microgrids and operators participate as suppliers, as well as consumers, of electricity services improves resource utilization. Ancillary services consume generating capacity. When loads provide these reserves, generating capacity is freed up to do what it was designed for, i.e., generate electricity. Additionally, smaller facilities will probably respond more quickly to control-center requests than large generators. This will likely more than overcome the communications and control delays associated with their greater numbers. Building owners and operators should be a more reliable supplier of ancillary services than conventional generators. Because each facility will be supplying a smaller fraction of the total system requirement for each service, the failure of a single resource is less important. Just as a system with ten 100-MW power plants requires less contingency reserves than one with a single 1000-MW plant so too a system that utilizes a large aggregation of loads as a resource to supply reserves will require less redundancy in the basic resource than one that carries all of its reserves on a few large generators. There can still be common-mode failures in the facilities of the aggregator, but it is easier and cheaper to install redundancy in this portion of the system than with an entire 1000-MW generating plant.

For each ancillary service, the EMS would make a decision, most likely in a day ahead market, as to whether it would be profitable to supply the service, and at what price. The EMS would then bid in to the market, and shortly would find out if the bid were successful. If successful, the EMS would plan to supply the service the next day. One of the most significant services, spinning reserve, is sold like insurance. The microgrid would be paid for supplying the service regardless of whether it is called for, and it should be called for only infrequently. The bidding and dispatching could be done automatically with only periodic operator oversight.

7.1.1. *Reactive Supply and Voltage Control*

Reactive supply and voltage control is the injection and absorption of reactive power from generators to control transmission voltages. Reactive supply and voltage control are required both to regulate distribution voltage and to maintain bulk power system reliability and are being opened to competitive markets in regions where RTOs operate. [22] This should not be confused with regulation, which is the service of the minute-to-minute generation/load balance to meet NERC's Control Performance Standard 1 and 2. Microgrids may or may not be able to sell Reactive Supply and Voltage Control depending on their size and location.

Voltage regulation will be performed locally in response to settings dispatched by the distribution system automation model. Typically, voltage regulation is done now by switching in capacitors or using voltage regulators on the feeders. A much more economical method would be by dispatching reactive power from local DER in response to sensed local voltage. A significant advantage of supplying reactive power from generation is that the effect of the power becomes even more pronounced as the distribution system voltage sags. Reactive power supplied from capacitor banks drops off with the square of the voltage. This is one of the most significant causes of voltage collapse. In addition, supplying reactive power and real power locally will reduce losses on the feeders and make the entire distribution circuit more efficient and less susceptible to voltage collapse. Finally, reactive power could be dynamically controlled and supplied as needed rather than being connected in blocks as capacitors are.

Voltage control from central generation is generally accomplished by sending the generator a setpoint for voltage. The generator is expected to respond rapidly to conditions that move the voltage away from its setpoint. Setpoint updates are not sent very often and can typically withstand a delay of a minute or two. For microgrids, the setpoint signal would be sent to the EMS, which would then dispatch its local generators.

7.1.2. *Supply of Reserves*

Viewed from the perspective of the power system, there are three ancillary services (reliability services) that microgrids might want to sell to the power system operator. These services are required to maintain bulk power system reliability and are being opened to competitive markets. [23] These services (Frequency Responsive Spinning Reserve, Supplemental Reserve, and Backup Supply) deal with restoring the real-energy balance between generators and loads in the event a generator or transmission line trips off line suddenly. Selling one of these services to the power system requires that the EMS stand ready to either reduce the building load or increase generation (by the amount of reserve that it wishes to sell) when called upon to do so. These services are characterized by the required response time, the response duration, and the communications and control required to facilitate the service. Figure 7.1 shows the required response times for these three energy-balancing functions.

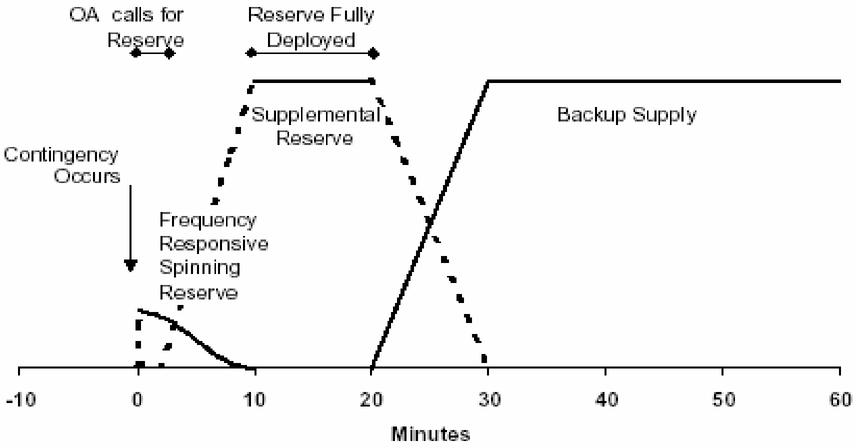

Figure 7.1. Required Response Times for Three Ancillary Services Buildings Might Sell

Frequency Responsive Spinning Reserve: Immediate (<10 seconds) response to contingencies and frequency deviations
Supplemental reserve: Response to restore generation/load balance within 10 minutes of a generation or transmission contingency
Backup Supply: Customer plan to restore system contingency reserves within 30 minutes if the customer's primary supply is disabled

Whenever a system operator calls for the deployment of contingency reserves there is always some chance that the resource that is supposed to supply the reserve will fail to do so. The small size of individual distributed resources reduces the consequence of this problem and makes them a more reliable source of contingency reserves. Take, for example, the case of a system operator purchasing 100 MW of supplemental operating reserve from a 100 MW fast-start combustion turbine. This turbine might start within the required time on 90% of its attempts. In one case in ten the system operator is 100 MW short. It does the system operator little good to reduce its expectations to 90 MW, though that is the average response.

A collection of 1,250 100 kW microgrids that individually may have only an 80% probability of responding each time makes a better aggregated resource. In this case 20% of the individuals fail to respond but the system operator still sees the full 100 MW response each time.

Energy and ancillary services (reliability services) are traded on bulk power markets with prices changing hourly or faster. The idea that microgrids can and should participate in these markets is gaining increasing acceptance. A microgrid whose building can respond to real-time energy prices can reduce energy costs because prices are increasingly volatile. Spot energy prices in the Midwest now span a 500:1 range. To exploit these price differences, a microgrid needs to be able to control building energy consumption, consuming when prices are low and avoiding consumption during the intervals when prices are high. Building owners and operators that are unwilling or unable to curtail consumption for the intervals when spot prices are high (typically lasting for several hours) may profit by selling contingency reserves to the power system. Reducing consumption for as short as10 minutes during a power system contingency can command a high price.

> ***Frequency Responsive Spinning Reserve*** is both easier and more difficult for distributed resources to provide. Because the service responds to system frequency, each facility has the triggering signal available at all times. Full response is required within 10 seconds (the specific time is ill-defined but it is certainly within seconds); which should be within the capability of many small generator types. The service creates a shorter interruption and only has to be provided until it is replaced by Supplemental Reserve (i.e., within 10 minutes). This service is a very real possibility for microgrids. Frequency responsive and supplemental reserves restore the system's generation/load balance and maintain it for 30 minutes. Thirty minutes after a contingency occurs, the customer that was receiving the lost generation is responsible for making other arrangements or curtailing its load.
>
> ***Supplemental Reserve*** is a likely candidate for microgrids to provide to the power system. The resource must fully respond within 15 minutes of the contingency (within 10 minutes of the system operator's request). Response must be maintained for an additional 20 minutes (i.e., until 30 minutes after the contingency). The system operator takes some of the 15 minutes to recognize the contingency and to call for response.
>
> The ***Backup Supply*** plan is a pre-arrangement that tells the system operator how to proceed for each load's loss of primary supply. Some microgrid generators may find it attractive to provide Backup Supply for other loads. The 30-minute warning provides time for communications and for the responding facility to take actions to reduce its own costs.

At first, these services appear to be similar to traditional utility load control, but there are major differences. Traditional load control provides little flexibility to customers. The customer must agree up front to be subject to utility load control, usually for a year or more. There is no ability to enter and leave the market as the customer's economic conditions change. The customer often gets paid a flat fee (or a reduced energy rate) independent of how or if the resource is actually used. This provides little flexibility for the load and little incentive to actually perform.

Providing a price signal that accurately reflects the real-time cost to provide the reserve service will encourage all suppliers, loads and generators, to offer supply when it is needed most. Real-time electricity prices are volatile, they reflect the changing costs associated with balancing supply and demand in an environment where there is essentially no ability to store the traded commodity. Costs associated with the load and local generation change dynamically as well. In many cases it may be advantageous to sell reliability services to the power system. Avoiding peak prices may require reducing demand or increasing generation for 4 to 8 hours or longer, but selling contingency reserves may only require standing ready to reduce load for 10 to 30 minutes in the event of a power system contingency.

7.1.3. *Regulation and Load Following*

These two services are similar in that both follow temporal variations in system load and help the control area operator meet NERC Control Performance Standards. Microgrids, if aggregated together in sufficient quantities, perhaps tens of megawatts, could supply these services.

Regulation:
Regulation is the use of on line generating units that are equipped with automatic generation control (AGC) and that can change output quickly to track the moment to moment fluctuations in customer loads and unintended fluctuations in generation. In so doing, regulation helps to maintain interconnection frequency, minimize differences between actual and scheduled power flows between control areas, and match generation to load within the control area. This service is typically provided by an appropriately equipped generator that is connected to the grid and electrically close enough to the local area that physical and economic transmission limitations do not prevent the importation of this power.

Load Following:
Load following is the use of online generation equipment to track the intra- and inter-hour changes in customer loads. Load following differs from regulation in three important respects. First, it occurs over longer time intervals than regulation, 10 minutes or more rather than minute to minute, and is therefore likely to be provided by different generators. Second, the load following patterns of individual customers are highly correlated with each other, whereas the regulation patterns are largely uncorrelated. Third, load following changes are often predictable (e.g., because of the weather dependence of many loads) and have similar day-to-day patterns. Alternatively, the customer can inform the control center of impending changes in its electricity use; as a consequence, these changes can be captured with short term forecasting techniques.

These differences between regulation and load following have strong commercial implications. Regulation is a higher value service than load following because of the need for higher generator speed and maneuverability. Therefore, regulation is likely a more expensive service.

7.1.4. *Other Ancillary Services*

System Blackstart:

Blackstart is the capability to start generation without outside power and restore all or a major portion of the power system to service without support from outside after a total system collapse. Blackstart requires intimate control by the system operator. Deployment is extremely rare, however, so it is possible that voice communications with a local operator would be acceptable if the resource was at a manned facility with suitably trained operators. Blackstart appears to be a service that microgrids are qualified to sell since many microgrids are inherently capable of operating independently of the power system. To be useful to the power system, however, the blackstart units have to be located where they can be used and capable of re-starting other generators. Some microgrids may not be large enough or located properly to be useful. For those that are big enough and in the correct location this could be an excellent service to sell. Microgrids may be able to participate by aggregating and forming larger islands, which would then provide stability to the grid as it was restored.

Network Stability:

Network stability enhancement is a service that distributed generators and storage devices should excel at if they are connected to the power system through an inverter and are in the correct physical location. In the Western Interconnection, because of the long transmission distances between the generation and load, there is much more of a problem of low frequency oscillations across the system. These oscillations are a natural consequence of the operation of the system, and they normally die away due to the natural damping of the system. However, when the natural damping of the system has been weakened due to a disturbance (loss of a large generator), these oscillations can grow over several seconds until the oscillations become so severe that additional generators begin to trip, transmission lines are overloaded and begin to trip, and the system begins to come apart. It is possible that these low frequency oscillations could be sensed by the microgrids, and the microgrids could provide a service of damping the oscillations. This would be accomplished using the power electronic interface on the microturbines to supply power that was 180 degrees out of phase from the oscillation. If large aggregations of the microgrids were used, the damping effect would be truly significant.

The Western Electricity Coordinating Council (WECC) dynamic model has been evaluated for the effect of various DER properties and transmission grid stability. [24] This modeling has allowed the manipulation of DER properties such as inertia constants, exciter gain values and various other control parameters. It was found in the modeling that increasing the DER inertia benefits the transmission system stability for some cases, and is a detriment for some cases. The reasons for this are somewhat complicated, but are related to phase lag. This suggests that a controller could be developed so that DER could provide a significant net benefit to system stability.

It was also found that DER can have a significant beneficial impact on transmission stability by supplying reactive power at the distribution level. A unique aspect of reactive power supplied by DER is that the real and reactive power injection are maintained during system disturbances, such as voltage sags. Alternately, reactive power supplied from load is voltage dependent. This means that capacitor banks are really least effective when you need them the most, during a voltage sag. Grid stability is an area that is really outside the scope of this report, but these results point out the significant possibilities and the need for future research on DER's impact on stability.

7.2. Relationship with the Distribution System - Concerns and Possibilities

A key feature of the microgrid is that it will be seen by the distribution system as a single controllable load. Both the real and reactive power load can be controlled. The microgrid's impact on the distribution system is not only that of a load that does no harm, but also as a good citizen, which responds to the needs of the distribution system. In the future, the microgrid will be a resource that dynamically responds to a wide range of local needs.

7.2.1. *Disconnect During Voltage or Frequency Excursion per IEEE 1547*

The conventional utility philosophy for response to events on the distribution system, which cause voltage or frequency excursions, is to simply disconnect any distributed energy resource from the system. This approach is in compliance with the IEEE Standard presently being prepared for interconnection, IEEE 1547, which requires that DER separate from the distribution system in the event of a voltage or frequency excursion. The utility can then deal with the problem in its normal manner. This is a rather short sighted approach, as the microgrid can do much to help resolve the problem. This approach is, however, palatable to utilities, as they don't have to be concerned with additional fault current contribution for which they are not designed. In addition, the 1547 approach ensures that the DER will not be supplying power into a distribution system that is supposed to be de-energized, thus presenting a safety hazard to linesmen.

There are a number of specific relay functions, in addition to over and under voltage, which IEEE 1547 requires to be provided with distributed energy resources. These include anti-islanding and underfrequency protection. These relays are typically provided with the distributed resource. They will not be under the direct control of the EMS. They will be similar to the "on board" controls for the DER discussed in Section 2. The EMS will only be responsible for dispatching voltage and power. IEEE 1547 is intended to be a first step in DER interconnection. In the future, there will be many other services that the microgrid can supply to the distribution system such as voltage and frequency regulation and even grid stability.

7.2.2. *Taking Advantage of Services from Microgrids*

In contrast to the conventional model, the distribution system of the future will take full advantage of the services that can be supplied from microgrids. The Distribution System of the Future will provide local control authority for actions that must be taken quickly; transmission grid management and longer response time functions will still be provided from the central controller (i.e., ISO). However, the local controllers will control microgrids and will function to keep the distribution voltage and frequency within limits specified by the central control authority. The local controllers will dispatch reliability services (spinning reserve, black start, etc.) in response to commands from the central control authority.

The microgrids will operate in response to their own needs for CHP, reliability, power quality, and will be managed in response to market signals (price for electric power, gas, etc.) The microgrids will also operate in response to market signals for the reliability services. When microgrids represent only 5% of the net generation capacity in an area, market crises like the ones that have occurred in many areas of the nation over the last few years will be eliminated. The microgrids will have responded to the market signals long before the crises reach the proportions of several hundred times the normal price for energy. Finally, microgrids will help ensure that the distribution system is operated in a manner that maximizes overall efficiency (optimal use of fuels, minimizes losses and minimizes emissions).

Conventional protection schemes are designed primarily for one-way power flow from the source of supply (i.e., substation) to the load points. With two way power flow, conventional protective relaying and fusing based on fault current levels will not work properly because the fault current levels will vary greatly depending on the number of connected generators, system configuration, etc. This will require development of fault detection systems that can operate on a totally different paradigm than conventional relaying. This need is discussed further in Section 11, future research needs.

Microgrids will have the ability to rapidly change configuration, island, re-align, start and stop generation. The industry must confront questions such as, should islands be allowed to form in a random but controlled manner, or should the distribution system collapse be allowed only along preset lines? Small islands will help to prevent complete blackout, to maintain power to critical loads and to help in system restoration.

For example, islanding a portion of the distribution system is currently considered a serious safety risk. The utility requires the owner of the distributed generator to ensure that the generator cannot energize a distribution line that is intended to be dead. If the utility supply to the line is interrupted, the distributed generator must detect the departure of the utility and de-energize the line too. In many cases there may be no economic alternative to this mode of operation for existing distribution lines, as reconfiguring an existing feeder's protection scheme could be very expensive. The implementation and expense will be debated, but the basic philosophy of de-energizing under adverse conditions may be economically unavoidable. From the perspective of the overall system, however, this is not a desirable design philosophy because it defeats a primary benefit of distributed generation, increased reliability. It would be much better if the distribution feeder protection scheme was designed to exploit the distributed generators' ability to support an islanded system. The distributed generators could sell backup supply to other customers on the feeder, benefiting all parties including the host utility. Islanding is also included in Section 11 as a future research need.

Although it may be necessary to accept reduced benefits from distributed resources for the present, designers of distribution expansion should ensure that the full capabilities of distributed generation are supported in the future. Utilities will come under pressure for this solution from at least three directions. First, as microgrids and distributed generation manufacturers get more comfortable with basic energy production they will want to expand their range of operations. Second, state regulators will continue to pressure utilities to accept greater amounts of distributed generation. Finally, and perhaps most importantly, system operators will recognize that distributed generation can sell reliability services to the system.

System operators tend to be conservative and slow to adopt new technology, but they also like having a large pool of diverse resources to draw upon when the power system is under stress. They may provide the strongest impetus for change, with the power system actively recruiting distributed generation rather than fighting it. This may occur more quickly as FERC encourages RTOs since the system operator will organizationally be at greater distance from the traditional large generators.

8. SIGNIFICANT RELATIONSHIP WITH THE ENVIRONMENT

When used in Combined Heat and Power (CHP) applications, DER will both reduce and displace emissions from central electric power generation and from local heat generation. When the displaced emissions from both sources are considered, the potential for DER to reduce total emissions is remarkable. Ultimately, it will be the responsibility of the EMS to make operational decisions which result in the lowest net emission production. These decisions will be directed hopefully by the net impact of the DER/CHP use, including displaced emissions, and not just the local DER emissions production. This section discusses methods the EMS could use for minimizing pollutant deposition.

The EMS will most likely make DER dispatch decisions by operating in response to market signals. Hopefully, a reasonable and fair emissions tariff will be built into the market system so that the electric power supplied from the DER will be valued appropriately considering the net emissions reduction. This tariff could even be a function of time, season and location, so that at worst pollution times and locations, the tariff would be most attractive. This would provide a stimulus to the EMS to dispatch the DER at the optimum power level for minimizing net emissions, and at times which are the most favorable for minimizing the impact from emissions. This section also discusses environmental policy initiatives and existing regulatory guidance.

8.1. Minimizing Pollutant Deposition Based on the Time of Use, Other Methods

The United States Environmental Protection Agency lists 6 criteria air pollutants for which ambient air limits have been set. These are nitrogen dioxide (NO_2), carbon monoxide (CO), sulfur dioxide (SO_2), lead (Pb), Ozone (O_3), and particulates. For microturbines operating on natural gas, there are three pollutants of interest: oxides of nitrogen (NOx), carbon monoxide (CO) and total hydrocarbons (THC). Generally, the emissions from microturbines are low for these three pollutants. The pollutant production of microturbines is a function of the operating temperature, power output, and other variables.

For example, Capstone emissions, although quite low, are still a function of the power level. [25] Capstone's sophisticated control system is designed to minimize emissions over a wide range of power output. NOx, CO and THC levels are at their lowest when the microturbine is operating over an output range between 90 and 100 % power. NOx formation is minimized at lower combustion temperatures, but lower combustion temperatures result in higher emissions of CO and THC. To resolve this, combustion of fuel must occur at the lowest possible temperature while the air and fuel mix must remain in the combustion chamber long enough to combust most of the fuel.

The fact that NOx, CO and THC are at their lowest at near 100% power is a fortunate result. This means that the EMS can dispatch the microturbine to supply heat to a process system at its full rating, and the electric power can be supplied with minimum emissions.

Minimizing emissions requires rapid and precise control of the combustion process. This rapid, expert control is best provided by the manufacturer's own control system, and not by the EMS. Factors the EMS may consider are the emission production vs. power level, the displaced emissions for both the heat output and electric power output, and, for some applications, that the remaining oxygen concentration in the engine exhaust is high, allowing the exhaust to be used in direct heating or as an air pre-heater for downstream burners.

Nationally, the two largest sources of NOx are electric power generating plants and highway vehicles. [26] Large gas turbines, reciprocating engines and reformers typically involve high temperatures that result in NOx production. Microturbines and fuel cells have much lower NOx emissions because of their lower combustion temperatures. NOx is a precursor pollutant to Ozone.

In general, large gas turbines have low emissions of carbon monoxide, particulates and sulfur oxides, but their NOx emissions are unacceptably high without controls, such as temperature and residence time in the combustion. As discussed above, the microturbine manufacturers have very close control over these factors to suppress NOx formation. Large turbine manufacturers use methods such as Wet Diluent Injection (WDI) where water or steam is injected into the combustion zone to moderate the temperature. WDI tends to increase CO emissions however, as well as reducing efficiency and shortening equipment life. Another method is use of catalytic reduction with agents such as ammonia in the exhaust. This is expensive and results sometimes in further problems, such as the formation of ammonia sulfate in the exhaust. There are also methods being developed with catalytic combustors; these use noble metal catalysts allowing high gas flow rates and very low pressure drop. [27]

A great deal of effort has gone into developing algorithms for environmental - economic dispatch of electric generation. [28] The methods usually use atmospheric emissions (e.g. NOx or SO2) as a weighted function in the overall dispatch algorithm. In CHP applications, usually the heat production is optimized, then the power production. That is, the power production follows the heat needs.

For large-scale CHP district systems, the constraints may be as follows:

1. The total power generation should equal the demand at each hour, or power must be purchased.
2. The heat generation must equal the heat demand in each hour.
3. The emission of SO2, NOx and CO2 must not exceed the limits.

To provide an appropriate weighting factor for each of these constraints, shadow prices are sometimes developed. Shadow prices are a mathematical tool that provides a measure of the importance of the variable. Shadow prices can be a function of the present real price, the demand, and the time; shadow prices may be developed for each hour. Shadow prices can be established for each of the pollutants, as well as for power and heat, and economically optimum solutions can be developed using an iterative method. The shadow prices, and the optimum dispatch solution, would be calculated by the EMS.

Ozone tends to peak in late spring and into summer as temperatures warm. [26] Because of lengthy reaction times, peak ozone concentrations frequently occur significantly downwind of source areas. Ozone tends to concentrate in densely populated areas, so high levels can occur at considerable distances downwind from urban centers. Examples of this are the high ozone levels that occur in Northern California, downwind from the San Francisco bay area, and the high ozone levels that occur in the Smoky Mountains, downwind from Atlanta.

During seasons with warmer temperatures, it would be desirable to minimize NOx production in or near large urban areas. Microgrids using microturbines in CHP applications would be effective in accomplishing this. Appropriate rate incentives, based on specific pollutant production, displaced emissions, the expected temperature, and other significant factors could play an important role in controlling hazardous pollutant generation.

8.2. Policy Initiatives

Surveys of DER installation sites have found that the most challenging aspects of the siting and permitting process were the paperwork, regulatory interpretation process, and annual testing involved with getting an air pollution permit. The most costly aspects were on site testing. The permit process could be greatly streamlined if microturbines and other DER could be pre-qualified as meeting an acceptable minimum standard. Ideally these standards would also form the basis for the local codes.

The Clean Air Act is the federal government's principal mechanism for controlling emissions. This legislation requires that the states regulate the level of emissions produced by various types of machinery. Each local air district must submit to the EPA a plan, which demonstrates a strategy for controlling emissions and a model, which shows that the strategy will decrease pollutants. Newly permitted combustion sources must demonstrate "BACT", the Best Available Control Technology for the regulated pollutants. Determining which regulations apply to a given source is complex and is usually done on a case-by-case basis.

One of the most important aspects of environmental impact that must be considered is that DER used in a CHP application will displace both the emissions from electric power generation and from heating and/or cooling production. This fact is often not considered in today's regulations.

The net reduction in carbon emissions that could result from new CHP systems have been estimated in a study: P.L. Lemar, The Potential Impact of Policies to Promote Combined

Heat and Power in US Industry. [29] This study evaluated the impact of CHP on improving the overall efficiency of fuel utilization. The study considered three CHP development scenarios, a Business As Usual scenario, a moderate scenario and an advanced scenario. In the moderate scenario, tax credits were given for CHP projects, guidance was provided to state agencies on establishing faster CHP permitting processes, and a national interconnection standard was developed. In the advanced scenario, tax credits were extended beyond 2003 and state grants were increased to encourage streamlined CHP siting and permitting. In the moderate scenario, emission reductions of 9.7 million tons of carbon were achieved by 2020, and reductions of 39.7 tons by 2020 in an advanced scenario.

8.3 California Air Resources Board Guidance

The California EPA Air Resources Board (ARB) has provided guidance for the permitting of electrical generation technologies: Guidance for the Permitting of Electrical Generation Technologies [30]. The board has recommended emission levels that are based on the rating of the equipment, and also whether the equipment is used in a combined cycle application, and whether it uses waste gas as fuel. The levels are summarized in the following table. It is the goal that the smaller generators will have the same emission levels as the central station plants.

Table 8.1 Summary Of BACT For The Control Of Emissions From Stationary GasTurbines Used In Electrical Generation*

Equipment Category	NOx (lb/MW-hr)	VOC (lb/MW-hr)	CO (lb/MW-hr)
Less than 3 MW	0.5	0.1	0.4
3 – 12 MW			
Combined cycle	0.12	0.04	0.2
Simple cycle	0.25	0.04	0.2
12 – 50 MW			
Combined cycle	0.10	0.03	0.15
Simple cycle	0.20	0.03	0.15
Waste gas fired	1.25	NA	NA

* All standards based on a 3-hour rolling average.

Table 8.2 Summary Of BACT For The Control Of Emissions From Reciprocating Engines Used In Electrical Generation

Equipment Category	NOx (lb/MW-hr)	VOC (lb/MW-hr)	CO (lb/MW-hr)	PM (lb/MW-hr)
Fossil fuel fired	0.5	0.5	1.9	0.06
Waste gas fired	1.9	1.9	7.8	NA

Note that the requirements are less stringent for smaller turbines. These emission levels are to be used by Districts in California as a starting point in conducting a case-by-case BACT determination. There may be feasible technologies that will reduce emissions further. The specific conditions of each application may justify a departure from the ARB's staff recommended BACT emission levels.

The Air Resources Board considers microturbines to be an emerging technology generally sized (30 to 75 kW) below the permitting threshold for gas turbines. Thus, no BACT determinations have been made for this equipment category. Beginning in January 1, 2003, emissions from new microturbines will be regulated through the ARB DG certification program. The ARB staff recommends that Districts permitting microturbines after January 1, 2003 require the units to be certified by the ARB DG certification program.

A fuel cell is a relatively clean electrochemical device that combines hydrogen with oxygen from the air to produce electricity, heat, and water. Some Districts have added fuel cells to the list of equipment exempted from district permit requirements. Fuel cells themselves do not emit air pollutants, but the reformers used to supply the hydrogen fuel can emit small quantities of pollutants. Source tests conducted on a fuel cell with a reformer indicate that emissions of NOx are about 2 ppmvd at 15 percent O2 or about 0.06 lb/MW-hr, near the emission level of a central station power plant equipped with BACT.

In the future, the ARB is going to make its BACT determination guidance to the districts equivalent to that of permitted central station power plants in California. Control technologies and conversion efficiency from fossil fuel to electrical energy will need to improve.

Most importantly, the ARB staff is recommending that the achievement of central station power plant emission levels recognizes the contributions from combined heat and power applications (CHP). The ARB supports giving credit for process heat that can be used toward meeting the central station power plant emission level. CHP can increase efficiency of energy conversion to over 80 percent. The ARB recommends that the facilities overall emissions rate in lb/MW-hr be determined by dividing the emissions of the facility, on a pollutant by pollutant basis, by the facility's total energy production. The total energy production being the sum of the net electrical production, in MW and the actual process heat consumed in a useful manner, converted to MW. This is an extremely important recommendation because it acknowledges the real contribution that CHP makes to emissions reduction, and provides a significant first step to future regulatory action across the nation.

9. POSSIBLE EMS COMMUNICATION WITH THE UTILITY OR INDEPENDENT SYSTEM OPERATOR

This section describes possible protocols and communication methods for EMS communication. A discussion of the function of the gateway in providing connectivity between devices is provided along with the challenges that face the gateway technology. A low cost, reliable standardized communication gateway must be developed.

9.1 Protocols and Communication Methods

Computers need rigidly defined procedures for communication. Often the procedures used by the system operator, or ISO, and the microturbine, the heat recovery devices, and the local EMS are all different. In the ideal world, the EMS will provide a translation service for these different communication methods and provide a common basis for communication with all the different entities - the owner, the ISO, the generation equipment, and even the control valves and sensors. A device performing these translations is called a gateway. The gateway provides connectivity between devices. The gateway performs message translating, formatting, routing and signaling functions.

Gateways can also introduce time delays and other problems when exchanging information. The report, "Communication Gateways, Friend or Foe," provides an excellent discussion. [31]

> "In addition to the processing time needed to do the translation, the connected networks may have different transmission speeds and different rules for gaining access to the media that also contribute to the delay. Sometimes gateways are designed to only pass a limited amount of very specific information. The gateway may poll devices for this information and then store a local copy.
>
> When a request for this information is received the response is prepared by the gateway based on the local copy of the data. This approach does not scale easily to large systems. It can also result in result in old and misleading data... Gateways make troubleshooting network problems more difficult. Different tools are needed to see and interpret the protocols on both sides of the gateway. Any ambiguity introduced by the gateway's imperfect translation introduces the possibility of error. Even a limitation on the amount of information accessible through the gateway can make troubleshooting difficult, because it may not be possible to access all the information needed to diagnose the problem."

9.2 Alternative Communications

To avoid these problems, the Independent System Operators impose very strict technical requirements on the gateways used by generators. For example, the CAISO has different gateway requirements for different types of generation services. The most stringent requirements are for the Remote Intelligent Gateway (RIG), a gateway for generating units providing regulation or ancillary services. A simpler Data Processing Gateway (DPG) is specified for generating units providing only non-AGS ancillary services.

Some market participants receive dispatch instructions from the Automated Dispatch System (ADS). The ADS is for dispatch instructions that are provided on a much slower (hourly) time frame. The ISO provides the software, security cards and card readers for the ADS, the microgrid provides his own PC and operating software. It can be seen that the gateway cost is proportional to the time frame it operates in. The faster gateways that are used in critical, near real time applications have extensive requirements, but the simpler, hourly type are actually just software provided by the ISO and run on a local PC. A discussion of gateway features and design is beyond the scope of this report, but the point must be made that the gateway requirement and specification is a significant part of the EMS.

Can a gateway be developed that is available at a nominal cost and which would allow microgrids to supply the faster time frame ancillary services? Many of the larger scale EMS systems discussed in Phase 1 are based on communication systems and gateways that did not include typical utility SCADA systems, and would need significant modification to meet that standard. The authors believe that there is a strong possibility that a low cost, reliable, standardized gateway could be developed that would meet the needs of the utility or ISO and the needs of the EMS. Due to the very nature of the translation of differing computer communication procedures and control concepts, the configuration and programming of some functions and devices within the needed time frames is going to be challenging. A thorough national protocol development initiative would be needed to ensure that all functions, devices, and concepts are included in the standardized gateway. Discussion of this possibility is left with a future report.

10. BASIS FOR CHP ALGORITHMS

Researchers at the Oak Ridge National Laboratory have performed extensive testing on a microturbine connected to various types of heat recovery devices. This microturbine was installed at ORNL's Cooling, Heating, and Power Integration Laboratory, Figure 10.1. Using this testing, they have prepared a report that documents the development and validation of predictive algorithms for modeling the microturbine in a Building Combined Cooling, Heating and Power (BCHP) system. [32]

This section provides a discussion of the general structure and basic steps for developing a Building Combined Cooling, Heating and Power (BCHP) system model.

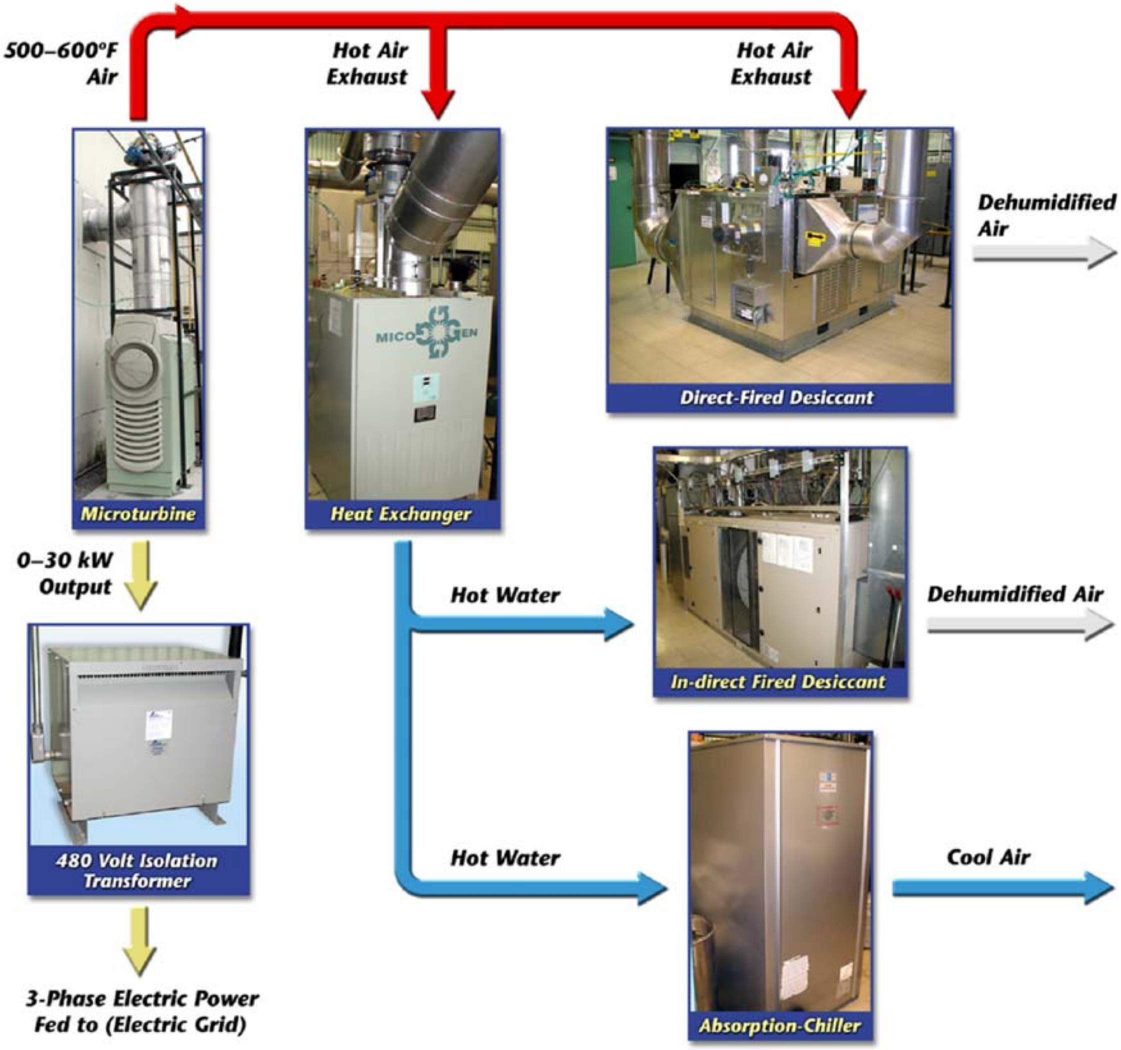

Figure 10.1. CHP Integration Test Facility at ORNL

The mathematical model developed at ORNL is based on a 30-kW, natural gas-fired microturbine, Figure 10.2; however, it can be extended to encompass a microturbine of any capacity and fuel-type. Both experimental and theoretical data are being used to model the BCHP system consisting of a combined microturbine and heat-recovery components and to determine ways to improve the overall BCHP system efficiency. The purpose of the study is to outline the basis for development of a BCHP model and to report on progress that has been made in regards to modeling microturbine operation with thermal recovery.

Figure 10.2. A 30-kW Natural Gas-Fired Microturbine (Located Outdoors)

The model developed to date has been validated by experimental data. The first step was the mathematical modeling of the natural gas-fired microturbine. The process involved developing the thermodynamic equations that describe the processes of compression and expansion in the compressor and turbine, respectively, and developing the heat balance and mechanical energy balance equations. The mathematical model was applied to the baseline performance data collected on the 30-kW, natural gas-fired microturbine unit under steady-state conditions at various loads and at various exhaust backpressures. The backpressures were to simulate various types of heat recovery devices.

Under these modes of operation, the basic operating parameters (temperatures, pressures, flows, voltages, currents, etc.) and the output power of the microturbine were measured, and its energy efficiency was calculated. With maximum externally applied backpressure, the model shows that the output power losses due to backpressure range from 3.5% for full output to 5.5% for one-third power, while the efficiency losses (decrease in efficiency) range from 2.5 to 4%, correspondingly. This is an encouraging result because it shows that the reduction in turbine efficiency is small when the exhaust heat is being used in a CHP application.

The thermal recovery components consist of an air-to-water heat exchanger, both an indirect-fired and a direct-fired desiccant dehumidifier, and an indirect-fired single-effect absorption chiller, as shown in Figure 10.3 In addition, the microturbine exhaust heat output can be varied by changing the power output to test different waste heat source conditions. The absorption chiller output can be used to cool the inlet air to the microturbine to increase its efficiency. This cooling may be particularly useful when outside ambient temperatures are high because the microturbine is located outdoors and its efficiency drops off with higher temperatures.

Air to Water Heat Exchanger

Indirect Fired Dessicant Dehumidifier

Direct Fired Desiccant Dehumidifier

Absorption Chiller (On Right)

Figure 10.3

The semi-empirical BCHP model that is being developed will provide a means of analyzing optimal system operation. The mathematical aspect of the model allows the microgrid to choose optimal operating conditions and predict parameter values for individual units and entire systems under various loads in both steady-state and dynamic operating modes. The experimental aspect of the model makes it possible to measure key parameters from a real-world BCHP system and its individual pieces of equipment and to adjust the model to accurately represent the operation of the system. The experimental research also provides a way to verify model simulations that analyze recommended equipment design modifications and operational recommendations. [33]

The semi-empirical BCHP mathematical model has a modular two-level structure, Figure 10.4. The first level of the model consists of mathematical models of the individual units, such as the microturbine, chiller, heat exchanger, desiccant dehumidifiers, etc. The basic structure of each model consists of equations describing thermodynamic, heat exchange, hydraulic, and thermophysical processes that are typical of a given type of unit.

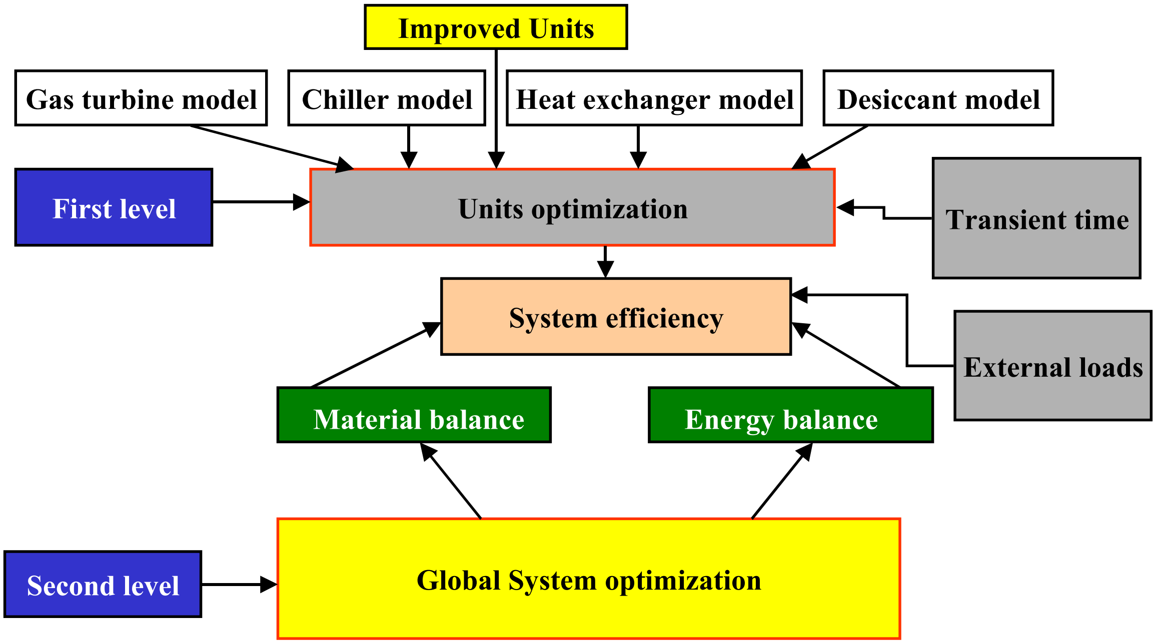

Figure 10.4. Semi-Empirical Mathematical Model of the BCHP System

The second level of the model includes the matrix of possible BCHP system configurations and provides for the combined solution of energy, material, and mechanical balances of the entire BCHP system. The *MathCad* software [34] is used to solve for the steady-state conditions of the model equations, and the *VisSim* software [35] is used to solve for the dynamic conditions of the BCHP system.

The model's second level also includes the following:

- the data library for the heating, cooling, and energy loads for different microgrids,
- the dynamic characteristics of the equipment,
- the special solution methods for optimizing sets of equations with free terms, and
- the interface that allows for interaction among levels and customer control over the configuration matrix.

The model follows the input air and fuel through the entire process including the air compressor, recuperator, combustion chamber, fuel oxidation, gas turbine, and the other units of the BCHP system. The other units are characterized by a growing backpressure at the outlet of the microturbine caused by the hydraulic resistance of the heat exchangers and other heat recovery equipment. As a result of the backpressure, the microturbine useful power and efficiency are reduced. This reduction has now been modeled.

The model will be invaluable for assessing the operation of numerous combinations of power generation and thermal recovery systems. Currently, the model is based on a microturbine-based power generation source. However, the modular form of the BCHP model would allow the addition of other power generation source models, such as fuel cells and reciprocating engines.

The mathematical model is being developed step by step in parallel with the experimental part of this project: the first-level models of the individual units are being developed first, and then the second level. To date only the microturbine and the heat recovery unit (Unifin Unit) mathematical models have been developed. The next steps will be to develop models for the other thermal recovery systems (indirect-fired absorption chiller, direct-fired and indirect fired desiccant dehumidifiers) and to incorporate these individual models into the overall BCHP model.

11. FUTURE RESEARCH NEEDS

<u>The Role of the Market System</u>: There are many competing demands, which must be assessed by a properly designed market system so that it sends the right signals to those bidding in to it. The owner of the microgrid will optimize the economics of his installation not only to satisfy his own needs for power, heat and back up supply, but also in accordance with the opportunities provided by the market. The market system would be designed to ensure that microgrid is rewarded for functioning as a good citizen, as follows:

1. Ensure that real time wholesale costs are reflected in the tariff so that microgrids could be responsive.
2. Permit microgrids to participate in the day ahead wholesale market.
3. Level load profiles have a significantly lower actual costs of service and this should be reflected in the rate.
4. The ancillary service markets should be opened so that microgrids could bid in.
5. Distributed resources can alleviate congestion across constrained transmission interfaces, and this could be quantified using locational pricing.
6. Markets for reactive load management, voltage regulation, and other demand side services are immature, and will remain uncertain until equitable market rules are established.

A research program is needed which would baseline the needs for DER and review existing market systems, both US and foreign, to see how these needs are met.

<u>Distribution and Transmission System Studies</u>: Microgrids can have a significant beneficial impact on transmission stability by supplying voltage independent reactive power at the distribution level. There are tremendous possibilities and a need for research on the microgrid's impact on load flow and stability. It is likely that a MW supplied in a stressed load pocket would have a much greater market value than one supplied from a distant generation station. Scoping studies should be performed to quantify the impact of locally supplied services vs. services supplied at the transmission level. Studies should also be performed to determine if microgrid Energy Management Systems could be programmed at various droop characteristics to provide voltage regulation and share reactive power similar to methods used in conventional generating stations. This studies should also be done for frequency droop characteristics to assess the microgrid's potential for supplying regulation.

Designers of distribution expansion should ensure that the full capabilities of distributed generation are supported in the future. Studies and demonstrations will help system operators to recognize that distributed generation can provide reliability services to the system.

System operators tend to be conservative, but they also like having a pool of diverse resources to draw upon when the power system is under stress. Case histories, studies and demonstrations will be valuable in changing the culture and acceptance of DER.

Environment: In the future, conversion efficiency from fossil fuel to electrical energy will need to improve for DER. Achievement of central station power plant emission levels must recognize the contributions from combined heat and power applications (CHP). The net effect of CHP towards reducing emissions in microgrid applications must be analyzed and benchmarked. The reductions must be demonstrated in a range of applications and geographic locations.

Communication Gateway: A gateway must be developed that is available at a nominal cost and which would allow microgrids to supply ancillary services. Many of the larger scale EMS systems discussed in Appendix A are based on communication systems and gateways that did not interface with typical utility SCADA systems, and would need significant modification to meet that standard. A low cost, reliable, standardized gateway should be developed that would meet the needs of the utility or ISO and the needs of the EMS. The translation of differing computer communication procedures and control concepts within the needed time frames is going to be challenging. A thorough national protocol development initiative is needed to ensure that all functions, devices, and concepts are included in the standardized gateway.

Ancillary Services from Microgrids: Microgrids are natural candidates to supply a number of ancillary services. For example, the topic of microgrids, equipped with energy storage, to supply regulation, is an interesting and exciting prospect. Contingency reserves, especially when microgrids close to the contingency are called to respond, could be a valuable service.

Relaying for Microgrids: Microgrids typically do not have the same levels of available fault current as conventional distribution systems. This is because many of the generators are equipped with inverters that limit fault current to perhaps twice normal rated current. This creates two concerns. First, conventional fusing and relaying designed to operate with large levels of fault current will not operate and clear faulted equipment. Second, when grid connected, even small levels of fault current (such as twice rated) when combined with the motor contribution, will cause problems with the conventional utility protective relaying in the distribution system. New relaying schemes and methods must be developed to address both of these concerns. One possibility within the microgrid is to use arcing fault sensors or ground fault sensors to detect faults. A possibility within the distribution system is to simply limit current flow into the distribution system to no more than the dispatched level. These concerns must be investigated and solutions must be developed and proven.

Islanding: It appears to be an obvious conclusion that microgrids must sometimes be capable of operating in an islanded mode. Islanding is needed so that critical processes and needs can still be operational in the event of a utility outage. However, should microgrids be allowed to join together to form larger islands? If so, how would this be controlled? Could these larger islands provide a black start service for the local utility, as discussed in Section 7? Islanding a portion of the distribution system is currently considered a serious safety risk. Islanding would, however, provide a primary benefit - increased reliability. Could the utility control and protection scheme be designed to exploit the microgrid's ability to island? These questions must be investigated and solutions developed.

References

1. Douglas Decker, "Federal Government: Building Management Systems/Utility Monitoring and Control Systems" Johnson Controls, Available: http://www.johnsoncontrols.com/cg-gov/art-utilitydereg.html

2. "Unifin Micogen Heat Recovery System Description" Unifin International Inc, 1030 Clarke Side Road, London, Ontario, Canada N6A 4P4.

3. Jim Heller, "Load Shifting with Thermal Energy Storage", *Navy ENews* 95b, Naval Facilities Engineering Service Center, Available: http://www.nfesc.navy.mil/

4. Figure provided courtesy of H.L. Willis and R.E. Brown, ABB Consulting, 940 Main Campus Drive, Suite 400, Raleigh, NC 27606

5. Eric Hirst and Brendan, Kirby, "What Is the Correct Time Averaging Period for the Regulation Ancillary Service?" Available: http://www.ornl.gov/ORNL/BTC/Restructuring/pub.htm

6. S.D. Labinov et al, "Predictive Algorithms for Microturbine Performance for BCCHP Systems"

7. Energy Info. Source's "DG Insight", Vol. 2, Issue 6, June 2002. Energy Info Source, 575 Union Blvd., Suite 107, Lakewood, CO 80228

8. R. Neal Elliott and Mark Spurr, "Combined Heat and Power: Capturing Wasted Energy", ACEEE, May, 1999 Available: http://www.aceee.org/pubs/

9. Douglas Hinrichs et al, "Integrated CHP Offers Efficiency Gains to Buildings Market", Energy User News, 9/27/01 Available: http://www.energyusernews.com

10. Owen Bailey et al, "An Engineering - Economic Analysis of Combined Heat and Power Technologies in a Micro Grid Application", Ernest Orlando Lawrence Berkeley National Laboratory, 1 Cyclotron Road, MS 90-4000, Berkeley, CA 94720-8061, March 29, 2002

11. Mary Ann Piette et al, "Analysis of an Information Monitoring and Diagnostic System to Improve Building Operations," *Energy and Buildings* 33 (2001) 783-791

12. E.H. Mathews, "Developing Cost Efficient Control Strategies to Ensure Optimal Energy Use and Sufficient Indoor Comfort," *Applied Energy* 66 (2000) 135-139

13. "CHP Overview" United States Combined Heating and Power Association, 2002, Available: http://www.nemw.org/uschpa/AboutCHP.htm

14. J. W. Jimison, *Why State Regulators Should Promote Combined Heat & Power*, U.S. Combined Heat and Power Association, A presentation to the NARUC, available at http://www.naruc.org/Committees/ere/j_jimison.pdf, 2002

15. E. H. Mathews, D. C. Arndt et al, "Developing Cost Efficient Control Strategies to Ensure Optimal Energy Use and Sufficient Indoor Comfort," published in *Applied Energy*, pp. 135-159, No. 66, 2000

16. Ref. *2001 Electricity Distribution Price Review*, Draft Decision, Office of the Regulator-General, Victoria, Melbourne, Australia, May 2000, 15601.

17. National Transmission Grid Study, U.S. Department of Energy, May 2002

18. ISO New England, *2001 Regional Transmission Expansion Plan*, available at www.iso-ne.com (see "Data and Reports"), 2001

19. J. Eto, J. Koomey et al, "Scoping Study on Trends in the Economic Value of Electricity Reliability to the U.S. Economy," LBNL-47911, Lawrence Berkeley National Laboratory, Berkeley, California, June 2001

20. Christine Hurley, "Economic Evaluation Tools for Distributed Generation", E Source Distributed Energy Service, DE-16, December, 2001, Platts, a Unit of the McGraw Hill Companies

21. Richard Cowart, "Efficient Reliability, The Critical Role of Demand Side Resources in Power Systems and Markets", the Regulatory Assistance Project, June, 2001, Available from: http://www.rapmaine.org/efficiency.html

22. Brendan Kirby and Eric Hirst, *Bulk-Power Reliability and Commercial Implications of Distributed Resources*, Feb. 5, 2,000, Available: http://www.ornl.gov/ORNL/BTC/Restructuring/pub.htm

23. B. Kirby and J. Kueck, "How Buildings Can Prosper by Interacting with Restructured Electricity Markets", ACEEE, 2000 ACEEE Summer Study on Energy Efficiency in Buildings, Available: http://www.ornl.gov/ORNL/BTC/Restructuring/pub.htm

24. R.T. Guttromson, "Modeling Distributed Energy Resource Dynamics on the Transmission System", Pacific Northwest National Laboratory, IEEE Paper # PE-093PRS, 06-2002)

25.Capstone Low Emissions MicroTurbine Technology, White Paper, March 6, 2000, Available: http://www.capstoneturbine.com/index.asp

26. Lasseter, R., A. Akhil, C. Marnay, J. Stephens, J. Dagle, R. Guttromson, A.S., Meliopoulous, R. Yinger, and J. Eto "Integration of Distributed Energy Resources: The CERTS MicroGrid Concept",April 2002, Available from: http://certs.lbl.gov/

27. S.R. Vatcha, "Low Emission Gas Turbines Using Catalytic Combustion", Energy Conversion Management, Vol. 38, No. 10-13, pp. 1327-1334

28. Peter Eriksen, "Economic and Environmental Dispatch of Power/CHP Production Sytems" , Electric Power Systems Research 57 (2001) 33-39, Elsevier Science S.A.

29. P.L. Lemar, "The Potential Impact of Policies to Promote Combined Heat and Power in US Industry", Energy Policy 29 (2001), Elsevier Science S.A

30. Guidance for the Permitting of Electrical Generation Technologies, As Approved by the Air Resources Board on November 15, 2001, Stationary Source Division, Project Assessment Branch, July, 2002, California Environmental Protection Agency

31. Steven T. Bushby, "Communication Gateways, Friend or Foe", ASHRAE Journal, April, 1998

32. S. D. Labinov, A. Zaltash, D. T. Rizy, P. D. Fairchild , R. C. DeVault, E. A. Vineyard**,** "Predictive Algorithms for Microturbine Performance for BCHP Systems", Proceedings of the 2002 ASHRAE Annual Meeting, Honolulu, Hawaii, June 22-26, Cooling, Heating and Power Group, Oak Ridge National Laboratory

33. A. Bejan, *Thermal Design and Optimization*, John Wiley and Sons, Inc., New York, New York, 1996.

34. Mathcad User's Guide, Mathcad and Mathcad PLUS 6.0, MathSoft Inc., Cambridge, Massachusetts, 1999

35. VisSim User's Guide, Version 4, Visual Solutions, Inc., Westford, Massachusetts, 1999.4

36. R. E. Chapman, "How Interoperability Saves Money," published in *ASHRAE Journal*, Atlanta, Georgia, Volume 43, February 2001, www.ashraejournal.org

APPENDIX A - Major Potential Vendors for the Energy Management System

This appendix lists a number of vendors for EMS systems or major components. Some are already offering large-scale EMS systems; and others produce highly flexible control systems that can be configured for a broad range of applications. The important point for each is that their systems are flexible and are usually custom designed. Any would be good choices for monitoring and control of a microgrid.

It is impossible to do justice to each manufacturer with only one or two paragraphs, however the following will provide a useful and reasonable summary:

1. Tridium, Inc. (www.tridium.com) produces Vykon, a web - enabled application specifically designed for the building automation and energy services industries. The Vykon system includes:

Vykon Building Control Suite Web SupervisorTM A flexible graphical user interface that provides traditional building management functions such as scheduling, trending, alarming, historical data collection and advanced energy management applications. Web Supervisor can be operated locally or via the Internet.

WorkPlace ProTM A single, user-friendly toolkit that allows you to integrate and manage multi-vendor devices and subsystems - from anywhere around the world via the Web.

JACE-NP® (Java Application Control Engine) A Web-enabled application server that provides integrated control and network management for many diverse building control devices. The JACE-NP is based upon a compact PC platform that is Windows NT network friendly and compatible with common Web browsers around the world.

JACE-501/502TM (Java Application Control Engine) The JACE-5 series are lower cost devices with similar functionality as the JACE-NP based upon an embedded PowerPC platform.

2. Engage Network Solutions (www.engagenet.com) produces the Active Energy Management System. The Active Energy Management System includes the Building Server, which is a communications gateway product for facilities management devices. The server provides Ethernet connectivity to serial based devices. Once a device is connected to Ethernet, the data stored within it can be shared, distributed and accessed through a local or wide area network. The server supports power monitors, chillers and other HVAC equipment, circuit breakers, generators, uninterruptible power supplies (UPS), programmable controllers, and other devices with analog or digital I/O. Engage also produces DGen. DGen is an advanced application that facilitates the automated use of distributed generation via the Internet. DGen can be utilized as a stand-alone offering or as part of an integrated suite of products. From DGen's intuitive interface you can configure, command, and control multiple remotely located generators. DGen supports alarming

with e-mail capabilities so you know when the alarm you set up was tripped no matter where you are. DGen can automatically switch on and off the generator when the need arises. You can turn on generators automatically from any alarmable event such as temperature, realtime energy price, energy demand, and many pre-defined conditions. DGen, when integrated with the SCADA module, can successfully control and monitor virtually any generator anywhere.

DGen Features:
Records any parameter the generator is capable of monitoring
Start and stop individual generators
Dispatch groups of generators with a single click
Perform financial analysis on sites/generation assets
Profile site energy usage
Profile generator parameters
Automatically dispatch generation
Utilize real time pricing feeds to determine when generators should be started/stopped
Use multi-language, multi-currency, multi-unit capabilities

3. Sutron (www.sutron.com) produces a wireless remote generator control system, in addition to many other monitoring and control systems.

Sutron engineers developed the GenCom system to meet the needs of remote generator control. The GenCom panel monitors performance of the generator and engine at each site. Parameters such as fuel level, oil pressure, engine temperature, engine speed, output voltage, frequency, phase balance, and output power are recorded and transmitted to the central control facility. At the central facility, a PC displays and records the parameters. If one of these parameters exceeds limits, the generator is automatically shut down and an alarm condition is relayed to the central facility. If the generator is set for auto-start, the operator at the remote console is informed that it has turned on. Sutron PC software gives the operator full control of all the generators located at the facility. Using the Sutron GenCom system, remote generators can be connected to a central control facility using any combination of line-of-sight radios, telephone lines, or fiber-optic links. With a local area network, multiple PCs can be connected to allow more than one user access to the GenCom system. Sutron also has extensive experience with SCADA systems installed over wide geographic areas.

4. Encorp (www.encorp.com) Encorp has done several installations using DER to improve power quality. Encorp has a rather complete set of tools for monitoring and controlling a microgrid. One tool aggregates several DER generators together to form one "Virtual Power Plant". Some of the features of the Encorp Generator Power Controller are as follows:

- Embedded PLC software module, IEC 1131-3 Programming Language (Ladder Logic)
- Communication through LONWORKS® AND Modbus ® (RS-232/485)
- UL recognized component

- Embedded software modules include synchronizer, true RMS real power sensor, VAR sharing, kW load sharing control with soft loading and unloading, base load control, VAR/PF control, protective relays and PLC
- Includes complete power metering and monitoring functions
- Utility-grade device
- Remote operation using a variety of communications and theVirtual Power Plant™ software
- Remote real and reactive power reference settings
- Programmable, separately isolated switch inputs and relay outputs
- Setup and configuration with standard PC (no handheld programmer required)

Some of the features of Encorp's "Virtual Power Plant" are:

Multi-site dispatch center
On-site and remote graphical metering, monitoring and control
Complete integrated solution
Real-time trending and data logging
Power transfer control and monitoring
Complete alarming and security features
Generator(s) and utility-tie circuit breaker status
Voltage and current harmonics monitoring/alarming
Engine parameter monitoring and protection
“Drill-down” within sites to monitor and control individual gensets
Aggregate total power produced from remote sites
Compatible with standard PC-based hardware

The Encorp system is designed for synchronous generators, and thus would not be appropriate for the initial microgrid test.

5. Invensys Energy Solutions (http://www.ies.invensys.com/) is comprised of several companies, including:

Local Area Power Control provides integrated, reliable, cost-effective power delivery system control and management solutions for on-site power generation.

Barber-Colman DYNA Products offers a full line of precision electronic governors for diesel and gas engines, plus associated load sharing and auto-synchronizing controls and accessories. They also design and manufacture engine governing controls, which include full authority engine management systems.

Premier Power Solutions designs and manufactures electrical distribution walls (EDW) and electrical distribution centers (EDC) that can be customized to meet specific application needs. An integrated solution, both the walls and the centers accommodate electrical distribution equipment, lighting and motor control, telephone and communications equipment, and energy management technology.

6. Wonderware (http://www.wonderware.com/home.htm) Wonderware® is an easy to use, flexible, control, monitoring and data analysis software tool with a multitude of plug in modules for obtaining data and sending commands to any conceivable sensor or controller. Wonderware introduced InTouch® in 1989, an easy to use graphical interface with a powerful graphics engine. Since then, the company has become the world's leading supplier of industrial automation software, with more than 100,000 installations worldwide and more than a 26 percent share of the human-machine interface (HMI) market.

Following the success of InTouch, Wonderware expanded its product line with more Windows-based software products that gave customers additional automation capabilities including resource tracking, a real-time factory database, PC-based control, batch management and remote data viewing. In 1997 Wonderware brought these individual products together in a single bundle called FactorySuite, the industry's first true integrated suite of industrial automation software.

FactorySuite 2000 includes an impressive library of 32- and 16-bit Wonderware I/O Servers for interfacing to a broad range of control and sensor devices on the plant floor…and beyond. More than 600 servers are currently available from Wonderware and over 100 partner companies, providing connections to PLCs, RTUs, DCSs, flow controllers, loop controllers, scales, gauges, bar code readers and other hardware devices from the biggest names in industrial automation including Allen-Bradley, Siemens, Modicon, and many others. Hardware devices can also be connected through InControl™ connectivity to SDS, DeviceNet, Interbus-S, Profibus DP and much more since InControl itself is an integrated I/O Server. New I/O Servers are frequently added to our server library. A current listing of servers is available on the Wonderware corporate web site. If by chance they don't have a server for your particular device, you can develop your own custom solution with the FactorySuite 2000 I/O Server Toolkit. What this means is that every device—on the factory floor or in the field—can connect to Wonderware applications.

Wonderware's In Touch product may be able to communicate directly with the microturbine depending on the data exchange method that Capstone uses. Wonderware uses Microsoft DDE (Dynamic Data Exchange) communication. If Capstone does not use this standard method, an OmniServer will also be required. The OmniServer is an I/O server, which interprets data coming in from a device, and delivers the data to the client program - Wonderware. The OmniServer will interpret essentially any data exchange method.

The Wonderware InTouch provides a way to develop an animated screen that will show each microturbine, the commanded power and voltage level, and the parameters provided over the data link from each microturbine, such as output current, voltage, power, speed, temperature, etc. The InTouch screen will also any display alarms and graphs of data that may be desired.

7. Capstone provides two systems that could possibly be used as energy management systems for the CERTS test.

First is the Capstone Remote Monitoring System (CRMS). The CRMS allows you to communicate locally with up to 40 microturbines. The microturbines are "daisy chained" together using their serial ports and an RS 232 ethernet connection. One turbine is the master and the rest are in the "slave" mode. Data provided from each microturbine includes control panels, strip charts, trend graphs, event alarms and automation panels. The load cycle and scheduler automatically starts, stops and commands power to the micro turbines locally or remotely. The event monitor logs starts, stops and faults. The turbines can either be set to provide a set power level, or to load follow. If they are load following, a compatible power meter must be purchased which provides a pulse count. The CRMS will load the turbines for the maximum fuel efficiency point. If you own several Capstone turbines, all you need to purchase is the software to run them with the CRMS. There is presently a system operating in New York with 24 Capstone microturbines operating in stand alone with the CRMS control.

The second system offered by Capstone is the Power Server CPS 100. The CPS 100 integrates up to 100 turbines into a single generation system with one point of control. The CPS100 contains a microprocessor, which provides high speed networking via one RS-232 connection or a modem. There is also internet command via TCP/IP. There is an interface to the power meter so that control can be load following/peak shaving and dual mode (grid connect/stand alone). The CPS100 will load the turbines for the maximum fuel efficiency point. The CPS100 will also balance runtime so that all turbines are run at the same number of hours over time. There are also analog and discrete inputs for communications from other plant equipment. There is presently a system with 50 microturbines operating in grid connect with the CPS100.

With their conventional design, when a Capstone turbine is in the stand-alone mode, it acts as a voltage source. That is, it regulates voltage and frequency and supplies current as needed by the load. It does not regulate voltage well enough to share reactive power flow. The turbines are all operated at essentially the same voltage. When the turbine is in the grid connect mode, it acts as a current source, that is, it follows the voltage and frequency of the grid, and regulates the current, or power output, to a preset value. That value can either be constant, or it can load follow if desired.

Also, with the conventional design, a rapid transfer from stand-alone to grid connect is not possible. The turbine must be shut down, reset, and then restarted. Overcurrent duty is provided by the turbine's battery through its inverter, but it is limited by the rating of the inverter to twice normal rated current.

Large Scale Systems

The following systems are designed more for industrial applications and would not be as simple to use for the initial small scale testing. They may be excellent choices for the full scale Energy Management System that must make decisions based on the owner's needs, market conditions, utility needs, environmental concerns, and near and long term planning, as described in the following sections.

7. Intellution (www.intellution.com)

Intellution is another industrial automation software product for monitoring and controlling manufacturing operations. iFIX is the SCADA component of the system, and will provide:

- Terminal Server
- Embedded VBA
- Real-time and historical trending
- VisiconX - easy database access
- Data collection and data management
- Comprehensive reporting
- Alarming and alarm management
- Alarm counter functionality
- Node-based security
- Networking
- Graphic Dynamo Wizards
- On-line configuration
- Process visualization
- Advanced Historian
- OLE for Process Control (OPC) Support
- ActiveX Control Support
- Supervisory Control
- Object-Oriented Graphics
- Secure Containment of ActiveX Controls
- Plug and Solve Architecture
- Workspace Development Environment

8. Rockwell RSView 32

RSView32™ is an integrated, component-based HMI for monitoring and controlling automation machines and processes. RSView32 expands your view with open technologies that provide unprecedented connectivity to other Rockwell Software products, Microsoft products, and third-party applications.

RSView32 was the first HMI software to: Open its graphic displays as OLE containers for ActiveX™ controls-with thousands of third-party ActiveX controls to choose from, you can drop ready-made solutions right into your projects. Develop an object model to expose portions of its core functionality, allowing RSView32 to easily interoperate with other component-based software products. Integrate Microsoft's popular Visual Basic® for Applications (VBA) as a built-in programming language allowing almost unlimited ways to customize your RSView32 projects Support OPC standards as both a server and a client for fast, reliable communications with a wide variety of hardware devices. Implement Add-On Architecture (AOA) technology to expand RSView32's functionality and integrate new features directly into RSView32's core.

9. Honeywell Experion PKS

Honeywell's Experion PKS provides an integrated platform for Honeywell's complete Process Knowledge Solution that goes beyond distributed control technology to facilitate knowledge sharing and workflow management. The system optimizes work processes, improves routing maintenance efficiencies and resolves process issues. Experion PKS integrates sophisticated asset management tools, such as a powerful loop assessment tool that provides non-invasive, systematic, identification of controller problems. These types of diagnostic tools are available even with older, non-digital field devices. The Experion PKS operating environment integrates alarm, event and alert process management tools. The PKS provides a common platform for a wide range of applications from basic control to collaborative production management.

10. Johnson Controls Metasys Building Automation System

The Metasys building automation system uses industry-leading technology to provide information that helps you manage buildings more efficiently. Metasys can help you decrease maintenance and utility costs while increasing occupant productivity and streamlining operations. And with the newly patented Data Visualization technology, operator productivity can be increased. The Metasys system is focused on gathering, organizing and presenting information in ways that let you efficiently provide a comfortable, productive and safe building environment. Connectivity to more than 700 Metasys Compatible Products from other companies allows unique capabilities and facility-wide efficiencies not available from other building automation systems.

From the beginning, Metasys was designed so that it would be easy to connect with other systems in your building. As buildings and building systems become more dynamic, the ability to share information and knowledge will be important to create environments that are safe, productive and efficient. As Information Technology and the Internet continue to revolutionize the way we all do business, it's important to know that the systems in your building have the ability to share information both up (to the enterprise level) and down (to the controller level), as well as horizontally to the other intelligent equipment in the building. Metasys Integrating Architecture is flexible and open to adapt to the needs of systems such as:

BACnet
LonMark
Internet Protocol
N2 Open Communications Protocol
Microsoft ActiveX
Open Database Connectivity (ODBC)
OLE for Process Control (OPC)
Fire Alarm Systems
Security Systems

11. Celerity Energy

Celerity makes a control system specifically designed for DER called the Networked Distributed Resource™ (NDR™) Facility. The Networked Distributed Resource™ (NDR™) facility creates value for both owners of on-site generation (gen-set owners) and energy providers. The system is designed for large engine generators with synchronous generators, as opposed to microturbines with power electronic interfaces. The NDR™ aggregates seldom used commercial and industrial standby generators to be used as reliable sources of capacity and energy to meet peak power demands, while increasing their reliability for use during emergencies.

The NDR™ is an integrated solution, combining complete generator control, paralleling/grid interconnection, generator protection, monitoring, metering and communications. Celerity Energy creates NDR™ facilities by using proprietary technology, which provides synchronization, control, protection and power monitoring of the gen-set. It also installs Sixth Dimension 6D iNet™ (see item 16 below), which provides an Internet-based communications platform to dispatch and control the generator's output. Both features are needed to connect generators in parallel with other generators and the utility's power grid. Energy providers can remotely control the NDR™ facility to reduce the need for expensive peaking power purchases and to alleviate capacity constraints and reliability issues while meeting emergency requirements. With this added resource they can defer expenditures for large-scale generation and/or transmission upgrades. The benefits are compelling.

The Celerity system would be ideal for a microgrid using synchronous machines because voltage and frequency are regulated and controlled within a set band. In addition, reactive power from each machine can be controlled. With the appropriate circuit breakers and relays, rapid closed transition transfer can be accomplished between stand alone and grid connected.

Engines with synchronous generators are typically sized by the designer to ensure that they can start the largest motor. Synchronous machines can cause problems with harmonic voltage distortion when they are supplying non linear loads. This is because they have a higher impedance than the normal utility source. They also may be limited in the fault current they provide. These problems can be addressed using energy storage, which Celerity also controls. At present, Celerity does provide control for microturbines and fuel cells, but there is no capability for reactive power sharing or synchronizing as there is with synchronous machines. Celerity also points out that harmonic distortion and stiffness are more of an issue with these sources in an island mode.

Celerity Energy assumes responsibility for maintenance and repair of the gen-set, freeing up maintenance dollars to the gen-set owner. Whether a hospital, airport, grocery store or office building, Celerity networks the generator with others and assumes the risk of performance and delivery of energy.

Celerity Energy aggregates capacity and related services in the form of dispatchable blocks of power, marketable by Celerity through its contractual commitments to the wholesale energy markets.

13. General Electric Energy Management System

GE's Energy Management System balances the sources of energy and the consumption of energy to achieve the lowest cost. These sources may be electricity, natural gas, oil, coal, steam or any other form of energy. The consumer could be anything from a manufacturing process to building heating to office lighting. GE's Energy Management System (EMS) controls energy consumption through monitoring and billing with GE's Cost Allocation Module (CAM) software, and controlling demand, energy flow and power quality with GE's Power Management Control (PMCS) software. The EMS consists of intelligent switchgear, motor controllers, meters connected to Ethernet networks, and a computer system equipped with software to collect, interpret, analyze, control and display the data obtained from the network. GE has a number of modules and systems, which may be integrated in many different ways to meet the needs of customers ranging from a small office building to a municipal utility.

14. Siemens Sinaut Spectrum Energy Management System

This is an upgradeable, flexible EMS for utility type systems. This EMS is designed for distribution companies, but is configurable for networks of any magnitude. This type of system may be appropriate for larger industrial parks and other situations where an actual utility distribution system is involved. It is not appropriate for the microgrid under test.

15. Connected Energy Corp. (CEC)

(CEC) offers an end-to-end solution to enable web-based remote management of distributed energy assets; such as generators, IC & EC engines, wind turbines, compressors, boilers and chillers. The end-to-end solution is branded COMSYS™ (Central Operation Management System), which gives the user telepresence; the ability to interact with equipment as if being physically there, without being physically there. COMSYS™ drives cost out of connecting and networking disparate energy assets both locally and over a wide area. By leveraging CEC's existing infrastructure, the customer can have trial sites online and software configured quickly and cost effectively when compared with competitive offerings. This allows the customer to conduct both internal and external "voice of the customer" studies at a fraction of the cost of competitive approaches. The applications can then be tuned to meet customer requirements prior to large-scale deployments.

The majority of capital equipment of interest have a simple controller to operate and locally monitor the equipment. CEC developed a third-generation interface to these OEM controllers called CENTRYwcc™ (Web Communications Controller or WCC) which is a device that enables low-cost connectivity to the OEM panel and its associated instrumentation points and to perform the real-time control functions. The WCC communicates with the equipment's controller via industrial protocols such as ModBus. Other protocols are supported by configuring the WCC to communicate as needed. The core of the WCC is an embedded web server, preloaded with a set of equipment-specific personality files to deliver a graphical user interface via standard web browser. Conceptually, each piece of equipment becomes a website on the local TCP/IP network that is constantly updating real-time data. The WCC is designed to be ordered and sold as a "black box" with built-in support for predetermined OEM controllers (selectable in the field) or licensed to OEMs for inclusion in their controllers from the production line.

The WCC uses enerTALK™ to send XML data out through an ethernet interface to a router and gateway to the Internet, and supports a "viewport" for technicians to plug into and/or for optional local monitoring and control. The WCC uses embedded Linux for an operating system and Apache as its webserver technology, and is packaged in a 2" x 4" x 5" space to allow easy mounting in the control panel.

The Facility Level

In addition to the WCC, a router to the Internet must be available to provide the gateway between the WCC devices on the local area network and the local Internet service provider. The COMSYS was designed as Internet-ready, requiring only firewall port 80 to be available. This overcomes a major concern of most onsite network administrators, opening up additional firewall ports. CEC has designed the system to connect via a secure virtual private network (VPN) connection with any Internet access such as: T1, phone line, DSL, cable, wireless, etc.

Machine Operation Management Center (MOMCenter)

Connected Energy also supplies the web back end. The MOMCenter includes the centralized servers, storage, applications, and monitoring center for all customer projects.

It provides remote control, system monitoring, and serves up browser-based customer interfaces and views to real-time plant data. It uses a high-speed database technology to deliver real-time data and has three primary categories of enterprise applications.

a. enerVIEW . This is a browser-based application giving an intuitive graphical representation of real-time views and data at the equipment. It includes key operating real-time and historical data values such as: energy consumption, energy production, machine alarm status, machine operating and health status. Control faceplate screens are also available through enerVIEW. Faceplates allow the operator to start, stop, load, unload and schedule the remote equipment.

b. reportsVIEW . Scheduled and on demand reports are available in HTML, .pdf and MS Word format through a standard browser. This is the approach to deliver a suite of reports served up in real time or scheduled depending on customer needs. CEC continues to build a suite of report applications for its customers, as well as a low-cost approach to rapidly create new reports. A few examples of reports includes:

KW/unit of product produced
Amount and cost of energy
consumption during plant shutdown
System efficiency (energy consumed/energy produced)
Reporting to support Best Practices programs between plants or stand alone sites

In today's competitive business environment, this is a tool you need to effectively manage distributed equipment. CEC's groundbreaking Central Operation Management System offers complete system monitoring, energy management, predictive maintenance, asset management, eparts solution and service coordination. Real-time and historical operation data and maintenance information is available to you at any time through a standard browser.

16. Sixth Dimension (6D) iNET (http://www.sixthdimension.com/)

Sixth Dimension (6D) iNET is a network approach that performs the following services:

- Facility metering/monitoring and control of generators and loads
- Performance-based operations and maintenance (single and multi-facility)
- Economic demand response and active load curtailment
- Aggregated distributed generation
- Power reliability, quality monitoring and analysis

6D iNET is the only network you need to bring energy services to market and grow your business -- fast. Whether you are planning to launch your first package of real-time energy services or extend your present line of services, 6D iNET is the right choice for fast growth and unlimited potential. This is the only service-delivery network that enables any brand of energy management software to communicate in real time and to control any device -- with the added reliability and security of 24/7 network management.

By delivering your energy services on 6D iNET, you can avoid the immense delay and cost of trying to build your own network, scale it up, and support it afterward. 6D iNET is ready to launch your energy services now. Many of the largest companies in the energy industry have discovered the value of concentrating on their core business -- building energy services based on their own business model -- and leaving the network operations to Sixth Dimension. 6D iNET is helping them to deliver high-value energy services with lower costs, lower technology risk, and a terrific competitive advantage. Like the operating system in your desktop computer, 6D iNET allows all of your energy applications -- created in-house or by any software provider -- to communicate with all of the devices at your customer locations. The 6D iNET Open Application Interface (6D iNET API) also provides direct access for all of your applications to access your data -- if you choose to store your data in our Tier 1 Data Center.

Secure, two-way communications for metering, monitoring and control guarantee that you have real-time access to all of your devices. 24/7 monitoring at our Network Operations Center continuously verifies that your devices are performing properly -- and provides immediate service when problems arise. Thanks to Distributed Intelligence, 6D iNET processing power and logic are located at each customer site, allowing you to add customers and change services at any time without expensive changes in network infrastructure.

17. Silicon Energy (http://www.siliconenergy.com)

Silicon Energy Corp. is a developer and seller of Internet-based energy technology software that enables enterprises to reduce energy costs and related expenditures. They offer a highly sophisticated program for energy management that includes many considerations in addition to dispatch of local generation. Silicon Energy's Enterprise Energy Management (EEM) is an integrated collection of software modules that enable enterprises and energy service providers to efficiently manage consumption, procurement and distributed energy assets. Silicon Energy allows real-time analysis and intelligent control over enterprise-wide energy usage, as well as comprehensive reporting and monitoring capabilities.

What significance does energy management make in an industrial manufacturing operation? Simply put, it could be the difference between profit and loss. A true measurement of energy reveals its cost variability and its significant impact on profit. When energy inefficiencies are left unchecked, even a small rise in energy costs can wipe out a slim profit margin. That problem is compounded when you lack a strategy to minimize risk to volatile energy markets. Enterprise Energy Management is defined by integrating all energy-related business processes into a complete management system to reduce costs, improve capital asset utilization and increase business efficiency.

The EEM Suite performs the following functions:

- Make real-time accurate decisions regarding energy costs as they relate to product manufacturing
- Integrate operational and analytic applications to measure productivity and improve predictability
- Benchmark energy facilities across the entire enterprise and develop a set of best practices for operations
- Maximize your leverage with energy suppliers to negotiate and procure the lowest rates
- Allocate costs across multiple production lines, departments or processes
- Generate alarms when your operations are likely to exceed contract terms for energy supply, or to comply with environmental and other regulatory requirements
- Determine marginal energy cost of production for various products and configurations
- Calculate the energy cost-effectiveness of different production strategies
- Optimize your own generation assets *by automatically determining when to rely on your local generation to minimize costs*
- Generate alarms based on actual usage and any other real-time operational parameters
- Determine per-unit cost of energy
- Generate all necessary information for competitive market RFPs
- Cost effectively utilize existing infrastructure (MES, process control, ERP, MIS, Intranet, Internet) by collecting and presenting all data on one platform