Training and Maintenance of Combined Heat and Power Systems

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ABSTRACT

This article focuses on the training and preventive maintenance of Combined Heat and Power (CHP) systems. Training for management of a CHP system should be done for all members of the team dedicated to its operation. The training should begin with a detailed overview of energy management and distributed generation technologies. A list of training topics providing a detailed understanding of the basics of distributed power generation is suggested in this study. Additionally, training for major equipments such as absorption chillers and microturbine technology is also addressed.

In developing a preventive maintenance program, the first step is to identify the critical equipment of a CHP system. Microturbine, absorption chiller, pumps and motors are critical equipment. The failure of the equipment can jeopardize the function of the system. To maintain an efficiently operating unit and avoid failure of critical equipment, it is necessary to maintain the critical parts of that equipment. In a successful preventive maintenance program all critical equipment should have three major components: system operation; operating logs, and scheduled inspections and maintenance. The management of the system does not end after the implementation and construction but is a continuous process.

Keywords: CHP training; preventive maintenance; microturbine; absorption chiller; pumps and motors

INTRODUCTION

Combined Heat and Power (CHP) generation is the cogeneration of electrical and thermal energy in a simultaneous process. CHP is not a specific technology, but rather an application of various technologies to meet the needs of the end-user. These needs vary from electrical generation, heating, cooling, steam generation, process heating and other unique forms of thermal energy and electrical energy utilization. With the ability to use more generated thermal energy, the system efficiency is increased.

In comparing a CHP system with conventional electric generation, the efficiency improvement is the first noticeable attribute. Approximately 1/3 of a fuel's potential energy is converted into usable energy in conventional generation. By implementing CHP, the system fuel demand is reduced by displacing a single or multiple component of the system with one that is driven by the thermal energy. For instance, if a facility is using a generator to produce electricity and using a boiler to produce steam from burning natural gas, the steam system could use the thermal energy during electrical generation to preheat the water, which would allow for less natural gas to be burned by the steam boiler.

There are numerous pieces of equipment that can be used as drivers for a CHP system. Gas turbines, reciprocating engines, fuel cells and microturbines are the major technologies that can provide the electrical and thermal demand that is needed. Each one of the movers is slightly different in the opportunities that can be provided. Choosing the correct distributed generation technology requires research and a complete understanding of the goal of the CHP system and a balance of the thermal and electrical requirements. That is the work of this thesis.

The thermal consumers of a CHP system are just as important as the electrical generators. The efficiency of distributed generators can range from as low as 15% to as high as 45%. This is still not efficient enough to operate and be cost effective. The key to a CHP system is to utilize the thermal energy efficiently as well. Hot water, steam driven equipment, space heating, desiccant dehumidifiers and absorption chillers are thermal consumers that can increase the efficiency of the CHP system to approximately 85%. This would make the system economically beneficial as well meet the reliability and environmental improvements. The combination of electrical generation equipment and thermal consuming technologies is vast and unique. The needs of the system will determine the right type of equipment that will be used.

CHP systems begin with an idea to improve energy efficiency and end with the ongoing management of the system. In order to achieve this management system, there must be additional studies that address the detailed design variables, contractual agreements and interconnection standards. These studies will lead to site plans and installation of the system. To successfully implement the system, the management must assign a team dedicated to the system development. This team will receive training to understand and maintain the system. The development of a CHP system requires training and preventative maintenance to achieve energy efficiency.

TRAINING

Training for management of a CHP system should be done for all members of the team dedicated to its operation. The training of the team members should be performed by licensed and skilled trainers who can provide the team with accurate technical information. There are two major types of training that should be made available to the team members.

Distributed Generation Training

The first type of training should begin with a detailed overview of energy management and distributed generation technologies. The detail of this training is relative to the skill sets of the CHP Team members. Most operational employees should be familiar with these technologies. This training should provide a detailed understanding of the basics of distributed power generation. Additionally, they should receive an overview of the equipment and the circumstances that are necessary in a successful distributed generation project.

A sample course agenda can be located in Table 1. The purpose of this course is to educate the team members with an advanced understanding of combined heat and power systems. This understanding gives the team the information and background of the CHP technology so that they may determine the tools applicable to the needs of the organization. Many times, third party consultants are brought in to analyze and decide the necessary components of the organization. Since the team members are already familiar with the present organization and its needs, they can be instrumental in assisting the consultants. This training should be a prerequisite to the training of the specific pieces of equipment.

Equipment Training

The proper use of CHP equipment is developed through specialized training. No one would consider using machinery or equipment without first ensuring that all those involved have received appropriate training on its use. Indeed, there is usually a right way and a wrong way of doing almost anything, even at a most basic level. The importance of training increases with the sophistication and complexity of the equipment.

Compared with studying only from manuals, it is far more effective to undertake product-specific training that allows hands-on experience to be gained with the actual components. In the system described in the previous chapters there are three major areas in which training

Table 1. Training Topics for Distributed Generation

Topic	Details
Overview	Terminology of power production History of distributed generation Applications of distributed power generation systems
Emissions Regulations and Impact	New regulations and their impact on generation Technology solutions How to work with regulatory bodies
CHP Installations	Utility attitudes toward CHP projects Review of projects
Engines and Engine Systems	Packaged systems and vendors System applications Technical fundamentals
Turbines & Microturbines	System applications and vendors History of microturbine development Technical fundamentals
Fuel Cells and Technology	System applications and vendors Process description Fuel cell components
Economic Analysis	Simple payback calculation Cost analysis of operating expenses Revenue streams and capital costs
Interconnection Standards	Project description History of interconnection standard development Government regulations
Case Study	Economic evaluation Cost analysis Technology assessment

is needed, the microturbine, absorption chiller and control system.

Training on these components may vary based on the actual design of the system. Each equipment manufacturer or supplier will provide training on the equipment that they provide. Additional training is also offered by a third party consultant on the equipment. In the event that the system is a modular system, training on the entire system is provided by the supplier. This training will involve the detailed working and maintenance of all parts of the system. The control system is the most vital training in that the operation and regulation of the CHP System is dependant on the controls.

In other designs, the specialized equipment may be independent and retrofitted to meet the needs of the system. Training of the equipment is typically included in the purchase price. This type of training is provided by the equipment manufacturer and encompasses specific details to the design, operation and maintenance of the equipment. The courses usually last one week, but longer training may be necessary for those team members who have not attended a course that provides the essentials.

A course on the absorption chillers should begin with a brief review of the absorption refrigeration cycle. Following the overview, the course should examine all product specifics, including construction, operation and control, required maintenance, service and troubleshooting for the absorption chiller and related parts. This course also should include coverage of the lithium bromide chemical cycle [1], the chemistry of inhibitors, specific discussion of capacity control systems for each chiller, crystallization control [2], purge system operation, performance and operator logging recommendations, and a heat balance discussion.

During this course, the team members will participate in hands-on activities on a fully operational absorption chiller. The team members must become familiar with the absorption chiller construction methods and learn to recognize the functions of all the components of the absorption chiller. A summary of the training topics is shown in Table 2.

The training course for microturbine would begin with an overview of the basics involving combustion and heat transfer [3]. Most of this material was taught in the introductory training and will refresh the team members on the basic operations of microturbines. The specific details will focus on understanding the basic operation of control and protection systems for proper startup, synchronization, load and shutdown of microturbines. The team members must be trained on

Table 2. Training Topics for Absorption Chiller

Topic	Details
Overview	Absorption refrigeration cycle Lithium bromide chemical cycle Chemistry of inhibitors
Product Specifics	Construction Operation and control Maintenance and troubleshooting
Performance	Capacity control system Crystallization causes and effects Purge system operation Performance and operator logging Heat balance
Hands-on	Installation Functions of components

the proper installation and regular maintenance techniques. It is also important that the team members develop a complete understanding of the theory of operation, design criteria and troubleshooting techniques in order to assist in and initiate corrective actions [4].

Each major component will come with a control system. Most systems are built with the capability of interacting with the other systems. The training for these systems will take place during the training of the equipment. Many systems are tied into a master control system used to monitor and operate the CHP System. These third party systems are provided with complete training and consulting services. A summary of the training topics for microturbines is shown in Table 3.

Table 3. Training Topics for Microturbine Technology

Topic	Details
Overview	Combustion Heat transfer Basic operations
Product Specifics	Control system Protection system Synchronization Load and shutdown Maintenance and troubleshooting
Performance	Theory of operation Design criteria
Hands-on	Installation Functions of components

PREVENTIVE MAINTENANCE

Preventive maintenance (PM) programs are a vital part of the operation of a CHP system. In a CHP system, the equipment which directly affects the performance of the system is considered critical equipment. Developing a special method for maintenance of the critical equipment is necessary for improving maintenance quality and reducing operating costs. This type of maintenance policy and strategy will improve the performance of the CHP system.

Preventive maintenance is a schedule of planned maintenance actions aimed at the prevention of breakdowns and failures. The primary goal of preventive maintenance is to prevent the failure of equipment before it actually occurs. It is designed to preserve and enhance equipment reliability by replacing worn components before they actually fail. Activities include equipment checks, partial or complete overhauls at specified periods, oil changes, lubrication and so on. In addition, workers can record equipment deterioration so they know to replace or repair worn parts before they cause system failure. Recent technological advances in tools for inspection and diagnosis have enabled even more accurate and effective equipment maintenance. The ideal preventive maintenance program would prevent all equipment failure before it occurs.

The first step in developing a preventive maintenance program is to identify the critical equipment of a CHP system. Microturbine, absorption chiller, pumps and motors are critical equipment. The failure of these pieces of equipment can jeopardize the function of the system. To maintain an efficiently operating unit and avoid failure of critical equipment, it is necessary to maintain the critical parts of that equipment. In a successful preventive maintenance program all critical equipment should have three major PM components: operating logs, scheduled inspections and scheduled maintenance.

Microturbine Preventive Maintenance

At this stage in the study, the microturbine is the recommended driver of the CHP system. The operation of the microturbine is the essential tool that is providing power and driving the absorption chiller. If the microturbine was to fail, the organization could still purchase power from the utility company, but the entire CHP system would shut down. A preventive maintenance program is an efficient way to keep the microturbine running as efficiently as possible. A sample preventive maintenance procedure is summarized in Table 4.

Table 4. Microturbine Preventive Maintenance

Activity	Procedure
System Operation	Test run for system regular basis Simulate problems Test run for components that do not operate extended periods
Monitoring Operation Log	Monitor fuel consumption Monitor power generation Monitor Waste heat
Scheduled Inspections and Maintenance	Perform daily inspections Downtime inspections if needed Service fuel compressors Replace parts Major overhaul

Power generation is not an efficient process. In order to be economically feasible, the efficiency must be raised. This is done with the addition of thermally activated equipment. The performance of the microturbine influences the overall efficiency of the system through power generation and the quality of energy produced from the waste heat.

One advantage of microturbine technology is that it has far fewer parts than other forms of distributed generation, which results in increased reliability and reduced maintenance. Microturbines are designed for continuous operation, therefore further reducing maintenance requirements. Regardless of the type of microturbine systems installed and the amount of time they are used, they require regular maintenance to function effectively and reliably. The maintenance of microturbines must be performed on two levels: testing the operation of the entire generation system and performing maintenance tasks on individual components.

Testing the operation of the entire system should be done on a regular basis to ensure efficient operation [5]. The test runs should be simulated to address the different problems that may occur. Systems that do not operate for extended periods of time should be test run in a simulated power failure. In this test run, the system should sense the failure, start, reach operating voltage and speed, and transfer and carry the necessary load. This simulation should continue for 30 minutes and be performed every two weeks.

The microturbine operation can run for an extended period of time. This type of operation is used to provide the base load for the designated buildings. It is important for the team to monitor the operation and to detect problems as they develop. Monitoring the operation can be done by analyzing the operating log [6]. This log will track the fuel consumption and power generation of the microturbine. Large variations in the ratio of consumption to production can show potential problems in the future. This log will also show the amount of waste heat being produced in relation to the consumption.

Scheduled inspections and maintenance should be performed in the microturbine maintenance program. The scheduled inspections should be done daily to make sure the equipment is operating to the highest efficiency. Since the microturbine does not have many moving parts, downtime inspections are not as common as other types of distributed generation equipment. Scheduled maintenance is very important to the operation of microturbines [7]. Typically, fuel compressors, air and fuel filters, the igniter, fuel injectors, and thermocouples will require service and replacement. A major overhaul may also be required that includes rotor replacement.

Absorption Chiller Preventive Maintenance

In a CHP system, the absorption chiller is the second most vital component, after the microturbine. The entire system's heating, ventilation and air-conditioning is dependant upon the operation of the absorption chiller. Proper preventive maintenance on an absorption chiller is critical for its efficient operation. The absorption chiller requires more preventative maintenance than the microturbine due to the filtration, water treatment and proper vacuum within the shell side of the absorber.

Neglect of the water treatment and filtration for an absorption chiller can cause poor air quality and corrosion inside the absorption chiller. Regular testing of the water should be done to make sure the water meets the environmental qualifications for the chiller system. Equally important is maintaining the proper vacuum within the shell side of the absorber. A loss of vacuum in an absorption chiller is usually the result of a leak which will reduce both the chiller's efficiency and its capacity. When a leak occurs, the oxygen from the air causes

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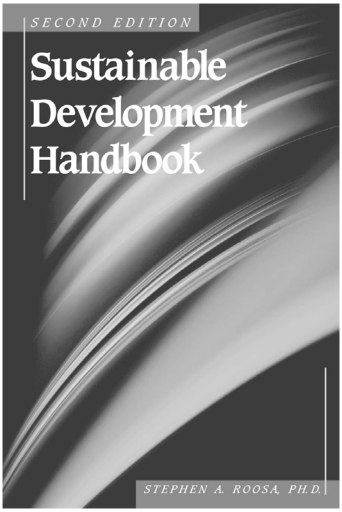

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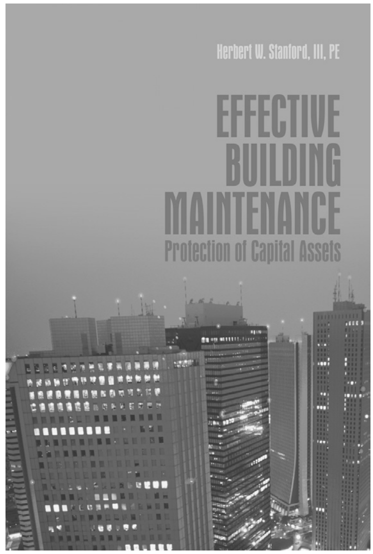

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the lithium bromide in the chiller to become extremely corrosive, damaging the unit's steel components. Using the purge unit can remove air from the unit, but the purge unit must be inspected regularly for proper operation, and its run time should be monitored to identify any developing leaks.

The operating log of the chiller is often overlooked and is one of the most valuable tools in chiller maintenance. This log tracks data related to the operation of the chiller, which allows operators and maintenance personnel to use this data to evaluate chiller performance. By analyzing the data, trends in the chiller performance that cannot be seen during daily operations may assist in troubleshooting and diagnosing chiller problems.

Scheduled inspections are also an important part of an absorption chiller preventive maintenance program. Scheduled inspections should be performed weekly, monthly or annually depending on what parts are inspected. The average chiller inspection requires only a couple of minutes and does not interfere with the regular operation. Since most organizations do not run on weekends or at night, the chiller can be shut down for more detailed inspections. It is recommended that the following PM inspections should be checked weekly: 1) any unusual noises and vibrations; 2) solution pumps and motors; 3) purge unit operation; 4) chilled and condenser water; and 5) the water treatment system.

Scheduled maintenance activities for absorption chillers should be based on the manufacturer's specification. These activities are based upon the number of hours and the conditions under which the system operates. The chiller system does not operate at full load year round, but the humid conditions that are faced during the summer months have an adverse affect on the chiller operation. The following are an example of maintenance items that should be checked on an annual or semiannual basis: 1) the purge unit's pump oil; 2) calibration of controls; 3) test chiller safety devices; 4) wiring, starters and disconnects; 5) chiller tubes for scale and fouling; and 6) the outside case for rust. A preventive maintenance program for the absorption chiller is necessary for the efficient operation of the CHP system. The physical plant and CHP team members need to establish the scheduling of inspections and maintenance of the absorption chiller. PM maintenance on this system can save an extensive amount of funds in the future. The preventive maintenance procedure is summarized in Table 5.

Table 5. Absorption Chiller Preventive Maintenance

Activity	Procedure
System Operation	Test water regularly Maintain proper vacuum Inspect purge unit
Operation Log Monitoring	Monitor drive motor currents and voltage Monitor condenser water supply and return temperature Monitor chilled water supply and return temperature Monitor Evaporator and condenser pressure, oil temperature and pressure
Schedule Inspections and Maintenance	Perform services weekly, monthly or annually based on parts

Pumps and Motors Preventive Maintenance

Pumps and motors are important pieces of equipment in the CHP system. Without pumps and motors the absorption chiller would not function properly. The pumps and motors provide the water to the system, from the system and transfer the conditioned air throughout the buildings. Preventive maintenance for pumps and motors is slightly different than for the microturbine and absorption chiller. A preventive maintenance programs for these two pieces of critical equipment lies in the monitoring and scheduled inspections.

Scheduled inspections and monitoring of pumps can identify potential problems. By monitoring pumps, the team members can identify problems with pressure, flow, noise, strain, liquid level and vibration. These problems can cause the pumps to use more energy and reduce the efficiency of the absorption chiller system. During downtime, the pumps can also be disassembled to identify other possible problems including wear, corrosion, discoloration and evidence of rubbing. The pump seal should also be checked regularly to prevent leakage and pressure drops.

The motors in the system drive the conditioned air throughout the buildings. By monitoring motors, the team could verify the motors are operating properly and without excessive vibration or heat. It is also important to lubricate the motors according to manufacturer recommendations. Over lubrication can be just as detrimental as under lubrication. Another area of inspection should be to make sure the drive system is properly adjusted and standard V-belts may be replaced with grooved belts or cogged belts to reduce drive system losses [8].

Motors should also be evaluated to make sure they are operating at the correct load percentage. Motors are usually sized to operate at 65 percent to 100 percent load and any motor less than 40 percent loaded should be replaced with a properly sized motor. Motor replacement should only be considered for inefficient motors, when it is not cost effective to rewind the motor. Motor preventive maintenance involves monitoring the motor performance and scheduling maintenance periods for disassemble. Also, if the motor load is continuously changing, a variable speed drive system may be installed to improve the overall system efficiency. The preventive maintenance procedure for pumps and motors is summarized in Table 6.

Table 6. Pumps and Motors Preventive Maintenance

Activity	Procedure
Pumps Monitoring	Identify problems with pressure, flow, noise, strain, liquid level and vibration
Pumps Inspections	Identify wear, corrosion, discoloration and evidence of rubbing Prevent leakage and pressure drops
Motors Monitoring/Inspections	Avoid excessive vibration or heat Lubricate parts Adjust drive system Replace grooved belts or cogged belts

CONCLUSIONS

In the development of a CHP system, the management should organize a team of operational personnel to be in charge of the CHP system. The objective of this team is to assist in the CHP studies, development and implementation of the CHP system. The team members need to be familiar with the present facility and the electrical and conditioning needs of the facility.

After the management forms the CHP team, the members should be trained in the various types of cogeneration equipment and CHP technology. This training should include equipment technology, interconnection standards, regulatory barriers and CHP economics. The team members will then be able to assist in the studies and development of the system.

Once the CHP system is approved and designed, the team members must receive specialized training on the equipment and control systems. This training will allow the team members to develop a preventive maintenance program and manage the system. Since a CHP system consists of critical equipment, the ability to monitor and maintain the system is vital for efficient operation.

Management of a CHP system begins with the development of the site plans. This step is deciding where the system should operate and from here the design of the system can take place. Once the system is designed, the management can begin the implementation process. The implementation of the system will set up the control parameters for the team to measure the day to day operations of the system. The management of the system does not end after the implementation and construction but is a continuous process.

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