Photo 1: This large commercial building in Gurgaon functions with an Energy Centre that generates 35MWe of power plus 18,000 TR of cooling. The equipment installed consists of 4 x 5 MW Gas Turbines with 4 x 3300 TR VAMs and 5 x 3 MW Gas Engines with 5 x 1100 TR VAMs

Energy Centres for CHP – Cooling, Heating & Power

By D.S. Kalsi
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Many parts of India suffer from a crippling shortage of electric power. Even though one can obtain a power connection from the electric grid of the State Electricity Board, see *Figure 1*, for a new building, one can never be sure that it will be available when one needs it the most, during the hot summer months when ambient temperatures can soar upto 40°C or even higher in northern parts of the country.

At the same time, the demand for office space, software parks, malls, hotels and hospitals is so great, that real estate developers find it difficult to resist the pressure to construct such buildings and earn good returns, instead of waiting many years for the Government to build additional power plants. Knowing fully well that many industries depend on captive power plants, within their premises, that operate on diesel oil, to maintain or expand their production, some developers concluded that they must do the same in their commercial complexes, specially with piped natural gas being available in many parts of the country.

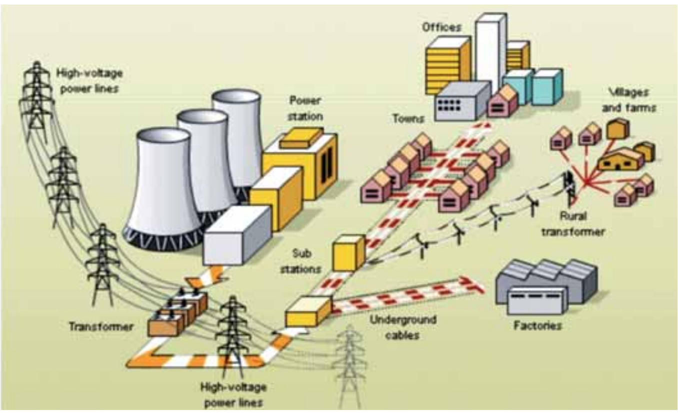

Figure 1: Electricity network in a typical grid, with power produced in one place and distributed to different places

So, these developers did extensive research, put their heads together with engineers, including some experienced with an HVAC background, since air conditioning plants consume 40% of the total power required for a building. They came up with a feasible plan to meet the demand. But, seeing is believing, and so, one large developer was bold enough to invest his money in a new shopping mall in NCR Delhi, where natural gas was available from GAIL, and together with an HVAC company, installed a 1.4 MW gas engine driven electric generator with the engine exhaust firing an absorption chiller to produce chilled water for cooling the building. This mall was commissioned in 2005, performed satisfactorily, and since then, the design and equipment has been replicated and refined over the years in many other larger commercial buildings and clusters of buildings in the NCR area.

About the Author

D.S. Kalsi has 15 years experience in design and engineering of HVAC&R systems. For the past 5 years he has worked with ICL and been involved in design of Energy Centres using heat recovery absorption chillers from BROAD China, process cooling both dry and adiabatic and turbine inlet air cooling projects.

What is an Energy Centre?

An Energy Centre is a combination of a Captive Power Plant (CPP) and District Cooling (DC) which serves one or more buildings in terms of power and HVAC. It is a housed in a plant room that has equipment which can generate self-sufficient power for building lighting and utilities and produce chilled water for air conditioning.

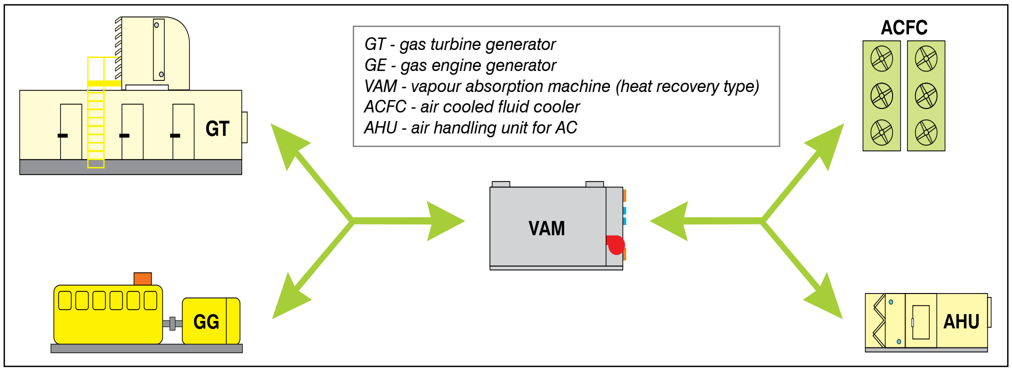

Figure 2: Power generation at site using gas engine and gas turbine with heat recovery chillers to produce chilled water for air conditioning

For building applications, CPP is designed with equipment like a diesel engine, gas engine or gas turbine. Power generation and DC are designed with a heat recovery absorption chiller. These are non-electric chillers. Turbine and engine efficiency is usually around 30% and 42% respectively. On utilizing the flue gases from the turbine and engine exhaust through a heat recovery chiller, the total system efficiency becomes more than 80%. Considering the diversity of load on electricity and HVAC, an Energy Centre proves to be an optimum solution. The complete requirement is restructured while designing the Energy Centre. It not only brings down the capital investment on power generation equipment, but also the operational cost.

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Why CPP with Heat Recovery Chillers only?

For a given building (or buildings) of total 1,000,000 sq.ft. area, the air conditioning load is 5,000 TR IPLV (Integrated Part Load Value). To run electric chillers of this capacity, it requires 4,000 KWe of power, if water cooled or 7,000 KWe if air cooled. Building utility and lighting required is 10,000 KWe.

Figure 3: Tri Energy Heat Recovery Chiller

Presuming the total electric load is 14,000 KWe (14 MWe), the building should be designed to get an electric connection of 14 MWe from the grid.

As power-cuts disrupt all activity in the building, therefore, 14 MWe of power backup is also required.

This adds upto 28 MWe of installed power in the building. With the availability of 28 MWe power the building (or buildings) can be considered operational and acceptable.

28 MWe installed power is considered acceptable with water cooled centrifugal electric chillers. It is clear from the above scenario (conventional method) that for one million sq.ft., 10 MWe electricity is required for lighting and utility as against the installed 28 MWe. If the above system is replaced with heat recovery chillers, the complete scenario changes. CPP (gas turbine and gas engine) is designed only for utilities and lighting. One 5 MWe of gas turbine and two 2.5 MWe gas engines can be installed to meet the requirement of 10 MWe. As a factor of safety, another two 2.5 MWe gas engines can be installed. If any engine is under maintenance or develops a fault then one redundant engine can take over. And if one gas turbine is under maintenance or develops a fault, then two redundant engines can take over the load. Therefore, the installed power becomes 15 MWe.

Advantages of a Heat Recovery Chiller

For air conditioning, a heat recovery chiller plays a major role. In fact, only due to heat recovery chillers, the Energy Centre turns out to be the best solution to achieve 80% system efficiency. Each engine and turbine is coupled with one heat recovery chiller. With a 5 MWe gas turbine, a 3300 TR chiller can be coupled. With a 2.5 MWe gas engine, approximately 900 TR chiller can be coupled. Hence, with one gas turbine and two gas engines in operation, the Energy Centre will produce 10 MWe of power and 5,100 TR of chilled water. Additionally, the heat recovery chillers can produce the same amount of chilled water without flue gases as they can be equipped with auto-modulating burners. These burners should be dual fuel. Natural gas, LPG or HSD can be used depending upon

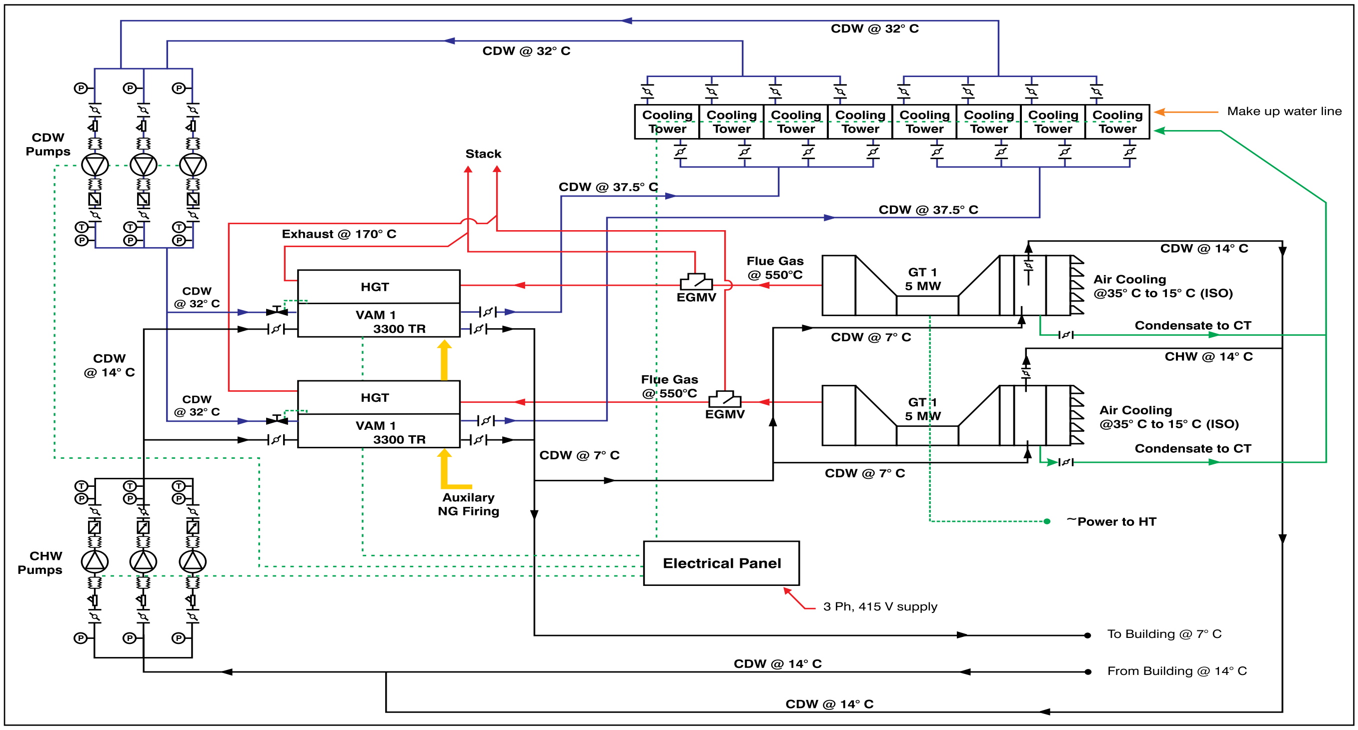

Figure 4: Typical flow diagram of power, air conditioning and turbine inlet air cooling

the availability. Even if the engine or turbine is non functional, these chillers can still produce chilled water, if required.

The feasibility of an Energy Centre clearly shows a saving in capital and operating cost. For the same building, capital investment is reduced in terms of non requirement of electricity from the grid. The complete dependability of power is on the installed equipment. The advantage is also in the reliability of power. In terms of operation, the building generates only 10 MWe of power for utilities and lighting. Sufficient and less power is generated due to non-electric heat recovery chillers. Further, the chillers produce chilled water by consuming flue gases. With respect to the conventional method, this type of Energy Centre is able to save tremendously on the operating cost. Hence, an Energy Centre not only reduces the load on the national grid but also helps in lower carbon emissions due to flue gas utilization. Extra electricity is not produced nor required due to non-electric chiller application.

The First Installation

In 2005, our company together with our principals in China who were producing heat recovery chillers for many years applied the above innovative design and commissioned a CHP project for a shopping mall using natural gas, fed to a 1.4 MW gas engine electric generator. The system performed favourably and the design was replicated in various large buildings based on diesel/gas engines and gas turbines.

It was for the first time in India that CHP was ever considered in a commercial building application where a large amount of cooling was required. Prior to this introduction of heat recovery chillers the design was restricted to industrial applications. Gas turbines were used in large size manufacturing industries only as captive power plants where the heat recovered from gas turbines was used in the HRSG (heat recovery steam generator) to produce steam and then run steam turbines. The steam could be also used to run steam fired absorption chillers for process or HVAC. Heat recovery chillers made it possible to install these even in commercial buildings. With the introduction of such chillers, steam turbines and HRSGs could be eliminated. This was never feasible earlier.

Space saving is also a major advantage in a commercial building which is expensive to build in urban areas.

Integrated Energy Systems

These highly efficient onsite/near-site energy plants combine distributed generation prime movers with thermally activated heat recovery equipment to simultaneously produce power, cooling and heating. Such systems are pre-engineered, optimizing use of the thermal energy output from the prime mover to provide space

Photo 2: A commercial building of one million sq. ft. functioning with an Energy Centre

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Photo 3: 2500TR heat recovery chiller coupled with a gas turbine

cooling and heating, process heat and dehumidification services to a building or campus, improving fuel utilization and overall energy efficiency. Modular in design, these systems are replicable and scalable, giving them the flexibility to serve a wide variety of municipal, commercial and industrial applications.

System Design

An Energy Centre recycles waste heat to drive an absorption chiller. The system design enables it to run solely on gas turbine exhaust or gas engines. The system doesn't need steam. Natural gas and hot water is an auxiliary to drive absorption chillers. It combines natural gas or HSD-fired combustion turbine generators to produce power with an advanced exhaust fired double-effect absorption chiller to produce cooling. The electricity can be used on-site and/or be exported and used by the project partners. *Figure 4* shows a typical flow diagram of the system.

System Performance

The plant installed in the buildings shown in *Photo 1* is one of the first successful installations of this type of Energy Centre to be completed on such a large scale. The gas turbine and gas engine exhaust heat evaporates water from lithium bromide (a natural absorbent). The resulting vapour condenses to produce chilled water at full capacity. A diverter valve and a stack are mounted between the turbine and the chiller to modulate the flow of exhaust through the chiller. This controls the amount of chilled water produced by the system. The combustion inlet cooling module uses a portion of the chilled water to cool the combustion turbine inlet air, improving the electric generator output on hot days as well as the system efficiency. The remaining chilled water output serves the site's cooling load by supplying a district chilled-water system.

Design

In this type of project design, engineers separate the equipment into seven components or modules:

- Inlet air filter and cooling module
- Gas compressor module
- Gas turbine module
- Absorption chiller module
- Chiller exhaust stack module
- Chilled water pump and control module
- Bypass damper stack module

Such a design allows the system the flexibility to be used in different capacity and space limitations. The modules come almost completely assembled by the manufacturers, making it easier to replicate and construct. They can be disconnected, mounted on trucks, and moved to new locations. This integrated Energy Centre design can be built at a customer's facility almost anywhere in the world. In addition, the standardized packaged design can cut capital costs by 15-30%. Lowering the initial costs of the energy centre shortens the payback period and allows on-site energy systems to be more competitive. Multi-use complexes have the advantage of diverse thermal loads. For example, a hospital requires continuous energy (24/7/365) while commercial buildings need energy during the day (peak periods of energy use), and residences need energy during the evening. By combining these building-energy use patterns, developers of mixed-use sites achieve more diverse thermal and electric load profiles that can be managed more efficiently - especially when an advanced Energy Centre is operated on-site.

Plant Operation

From purchase order to commercial operation, it takes nine months to build – about four months for engineering, materials procurement and fabrication, and five months for site construction. The system has the capability to vary electric and chilled-water load, but to maximize efficiency, it is primarily intended to operate in a base load configuration. At full load, the plants combined power and chilled-water efficiency is nearly 89 percent lower heat value (LHV), including equipment parasitic loads.

Photo 4: 5 MWe gas turbine package

Photo 5: Chilled & cooling water pump station

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Photo 6: 7x1.4 MW gas engine generators

Photo 7: 7x500 TR heat recovery chillers

A diverter valve installed between the turbine and high-stage generator section of the chiller allows chilled-water temperature control. A remote computer enables plant operators to monitor and control the system from a room 500 feet away from the CHP equipment. The electrical output is registered with the client and can be remotely dispatched to provide power to the required area whenever needed. The turbine generator can be up to full load in less than 15 minutes. However, the chiller requires an additional 30 minutes to heat soak the high stage generator section prior to achieving full load. The system is the first to use air quality standard permitting process for electric-generating units, which provides a thermal credit for CHP applications.

Cost of Natural Gas

A base-loaded CHP system will consume a constant flow of gas all days of the year. This stable and predictable throughput and capacity allows the CHP provider to negotiate favourable transportation and commodity pricing from the local distribution company and from a competitive gas supplier. Don't forget to ask the gas company about availability of high pressure gas. You don't want to install a gas compressor for your CHP system if the gas company can provide the pressures you need at little or no cost.

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Figure 8: Inlet air cooling of gas turbine

Ancillary and Parasitic Loads

No CHP system can operate without them, but how you pay for the fuel to operate your cooling towers, circulating pumps, gas compressor and other plant support equipment can have a significant impact on the financial performance of your CHP system. Most CHP installations will perform better financially by using the CHP prime mover as the source of power for the plant parasitic loads.

The configuration of large-scale absorption chillers in conjunction with combustion-turbine generators has proven to be effective for applications with large electric power, chilled-water and possibly hot water energy needs. With higher heating value efficiencies, in excess of 75%, fuel usage integrated energy systems using combustion turbine generators with absorption chillers should find a number of global applications.

CHP proves that by careful selection of system components, the options for replication of highly efficient and sustainable CHP plants are great. The choices for prime movers are increasing every year with new lean-burn reciprocating engines as well as highly efficient and low emission combustion turbines. Each of these prime movers can be mated with thermally activated chillers, desiccant driers or heat exchangers to maximize system efficiencies that will help us to sustain our energy needs.

Augmentation of Power

Since the chilled water is generated by the chillers for HVAC or process, the same can be used to cool the ambient air to ISO conditions, whereby enhancing power at the gas turbines. Usually in hot climates, the ambient temperature is to be brought down to ISO condition at 15°C to have the rated capacity from the turbine generator.

Conclusion

This article provides guidelines for building CHP systems. It is concluded by summarizing the main findings from the installations that may be used as a starting point either for future research or as an outline for system designers.