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Operation Planning of a Local Energy Supply System with a CCHP

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Abstract: *This paper presented an advent combined cooling, heating and power (CCHP) system which has provided the opportunity for in-house power backup for meeting the energy demands of Institutional sectors. Since energy demands kept increasing and optimally designed energy infrastructures should be able to satisfy all types of energy demand in the best interest of the end users. This plant system enjoys a symbiotic relationship between its components. In order to reduce waste from excess heat, hybrid chillers (absorption and electric) have been proposed to utilise the CCHP- produced thermal energy for cooling purpose. An EXCEL based tool and MATHLAB were developed to determine the dispatch strategies that minimise the overall cost of energy for the CCHP system. This paper also proffers a solution for such a system that accounts for electric, space heating, and space cooling load categories. In order to have a good insight into the study, several sensitivity analyses of the results are performed before drawing the conclusions.*
Keywords: *Absorption Chiller (ABC), Combined Cooling Heating and Power (CCHP), Efficiency, Electric Chiller (EC), Electric Grid (EG).*

I. Introduction

Before the introduction of CCHP, energy demands were met using the Traditional Separation Power (TSP). In other words, power is purchased directly from the Electric Grid to meet electricity demands. Similarly, a gas boiler will produce copious amounts of heat and warmth needed to meet the heat and cooling demands. In recent years, however, it seems that TSP system is not frequently in use, as this has been replaced by combined cooling, heating power (CCHP) system. For example, a CCHP system can be used for simultaneous production of these three energy demands [1] which is also called tri-generation system. Tri-generation, refers to a system of a cooling, heat and Power unit in conjunction with an absorption chiller (ABC) for generating electricity, heating and cooling [2]. Buildings with continuous or seasonal cooling demands can install tri-generation as a cost effective and low carbon way to achieve their heating and cooling demands. The waste heat produced by the CHP unit provides the required energy to produce chilled water. One of the most basic goals of CCHP systems is to ensure that, it is a more attractive option than TSP. The end goals of CCHP systems are to ensure reduction of primary energy, cost, emissions, or a combination of all of them [3]. All these features have stimulated the idea of moving from TSP, often with low efficiency to CCHP.

The flow of power in different energy infrastructures such as electricity and natural gas systems is therefore considered. The conversion of power between different energy carriers establishes a coupling of the corresponding power flows, resulting in system interactions. Fig. 1 shows the schematic diagram of a simple CCHP system. Electricity is purchased from the ED to meet the electricity and heat demand. Consequently, gas boiler is needed to supply additional heat needed by the building and also run the ABC to meet the cooling demand.

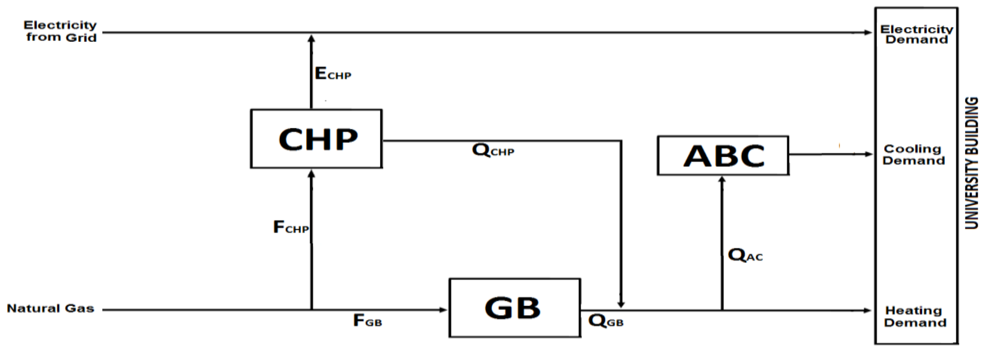

Figure Error! No text of specified style in document.: Schematic of a CCHP system

A CCHP system, as presented in this paper, is controlled to minimise energy cost and maximise efficiency. Therefore, investigations concerning tri-generation [4] should cover all involved energy carriers.

The use of CCHPs are now becoming more interesting and globally accepteddue to their high efficiency in meeting the electricity demand (ED), cooling demand (CD) and heat demand (HD) [1,5]. Unlike developed countries in Europe where the use of CCHP is much pronounced [6], development of this type of power generation remains in a primary stage in all the African countries. African countries are just making frantic efforts to develop its power generation network in different manner in order to give more efficient and reliable power supplies. It is noted that countries like Nigeria, South Africa, Tanzania and Tunisia are now gradually using the CHP to solve their energy problems [7]. With the growing availability of gas on the continent, coupled with unstable domestic power supplies, the market for CHP technology is now on the increase. In other word, CCHP system has been widely accepted as an alternative method to meet and solve energy related problems [5].

II. Various Components of a Typical CCHP System

Fig. 2 illustrates a more complex schematic diagram of a CCHP system with the inclusion of EC. The CCHP system allows an institution to generate its own electric power and use the rejected heat from the turbine to run an ABC or a heat recovery boiler to handle the possible cooling or the heating loads. Notice electric chiller (EC) uses electricity from the grid, CHP or both in providing additional cooling for the building. CCHP systems have an advantage over other types of cooling and heating equipment in that they use waste heat as a source of power and do not rely on primary energy, except for small auxiliary equipment [8-9].

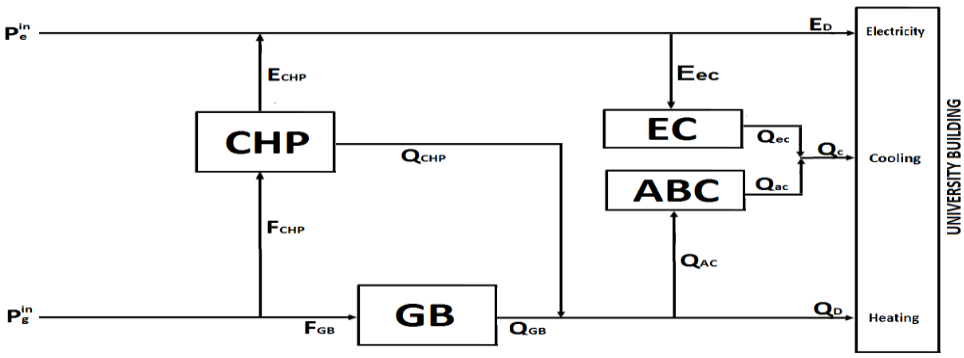

Figure 2: Schematic of a CCHP system with EC

A typical CCHP system has several options to fulfil energy requirements of its application. The electrical energy can be produced partially by a CHP and partially purchased from the electric grid (EG).This electric energy is used to power appliances and lights in the building and operate auxiliary cooling and heating components. If the CCHP does not produce enough electric energy to satisfy the electric demand, the difference can be imported from the EG. If there is excess supply of power by the CCHP, the excess could be sold back to the power grid or used to run the electric chiller to meet cooling demands of the building (Fig. 2). The main difference between CCHP systems and the typical methods of electric generation is the utilisation of the waste heat rejected from the prime mover in order to satisfy the thermal demand of a facility (cooling, heating, or hot water needs).

III. Modelling of a Simple CCHP System

The amount of electricity demand is the total sum of the electricity generated by the CHP and the electricity input from the grid. This can be represented as:

$$E_D = P_e^{in} + E_{CHP} \tag{1}$$

where

- E_D is the total electric energy used,
- P_e^{in} is the electricity input coming from the grid and
- E_{CHP} is the generated electricity by the CHP.

By expressing fuel consumed in terms of the amount of total gas intake by the CHP system with the dispatch factor v_b, total electricity demand becomes:

$$E_D = P_e^{in} + v_b P_g^{in} \eta_{el} \quad (2)$$

If the amount of fuel input required by the CHP to perform efficiently is determined by the ratio of power generated by the CHP to its electrical efficiency, then

$$F_{CHP} = \frac{E_{CHP}}{\eta_{el}} \quad (3)$$

The equation is presented in term of the total fuel consumption by the CHP by introducing a dispatch factor, v_b (Equation 4)

$$F_{CHP} = v_b P_g^{in} \quad (4)$$

where

- v_b is the dispatch factor
- P_g^{in} is the amount of gas input into the CHP
- The heat supplied to the absorption chiller by the CHP and the gas boiler can be estimated as

Expressing the heat parameters as a function of their respective efficiencies and dispatch factors v_a and v_b from Fig. 1 gives:

$$Q_D = (v_b\eta_{th} + \eta_{bo} + v_a\eta_{bo} - v_b\eta_{bo} - v_a v_b \eta_{th} - v_a v_b \eta_{bo}) P_g^{in} \quad (5)$$

Simplifying further by expressing the cooling demand and heat required by the absorption chiller in terms of dispatch factors (v_a and v_b) and their respectful efficiency gives:

$$Q_c = (v_a v_b \eta_{th}\eta_{ac} + v_a \eta_{bo}\eta_{ac} - v_a v_b \eta_{bo}\eta_{ac}) P_g^{in} \quad (6)$$

The coupling matrix equation where two inputs (electricity and gas) is to meet three energy demands (electricity, cooling and heating) is presented as:

$$\begin{bmatrix} E_D \\ Q_C \\ Q_D \end{bmatrix} = \begin{bmatrix} 1 - v_c & v_b\eta_{el} + v_b v_c \eta_{el} \\ v_c\eta_{ec} & v_b v_c \eta_{el}\eta_{ec} + v_a v_b \eta_{th}\eta_{ac} + \eta_{bo}\eta_{ac} - v_b\eta_{bo}\eta_{ac} \\ 0 & v_b\eta_{th} + \eta_{bo} + v_a v_b \eta_{bo} - v_b\eta_{bo} - v_a v_b \eta_{th} - v_a\eta_{bo} \end{bmatrix} \begin{bmatrix} P_e^{in} \\ P_g^{in} \end{bmatrix} \quad \textbf{(7)}$$

IV. Analysis And Discussion Of Results

It is assumed that heating, cooling and electricity demands are independent of each other. Fig. 3 presents the energy demands profile based on the available data. The Fig. also shows the variation of these energy demands for a period of one calendar year.

This paper also presents the results of optimisation for the CCHP system. Simulations for each climate conditions were performed to optimise CCHP operation with respect to the cost for a given Institution. The results help to determine the best operating system with lowest operating cost for the CCHP. Several sensitivity analyses were done to consider the variation of some key parameters of the optimisation model. The results show that when the CHP system is optimally put in use, cost of input energy is reduced which invariably reduce the operating cost.

It was found that the annual electricity demand of the University considered in this research work for a full calendar year was put at 56.08MWh, heat demand at 41.59MWh while the cooling demand was 26.93MWh.

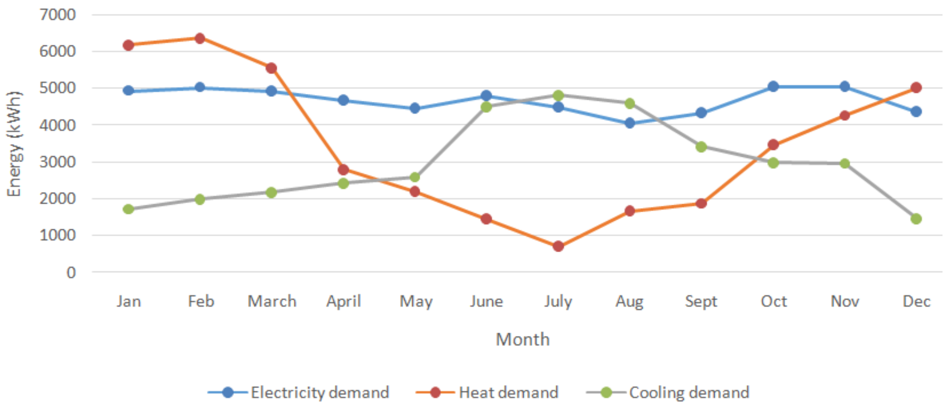

Figure 3: Energy Consumption for One Calendar Year

The electricity demands of the Institution is generally believed to have a transient behaviour since it is considerably depends on daily variations. For instance, energy usage depends on some factors such as the seasonal or weather variation of the year. Less electricity is consumed during the Summer period because students will be on vacation during this period, thereby reducing the number of electrical machines, appliances and other equipment used for lecture purposes. Unlike Winter season, less heating gadgets will be powered. Apart from the external influences, the electricity demand is majorly affected by the occupancy of the building. During the Summer period, most of the staff are on annual leave thereby reducing the numbers of people operating the electronics equipment and powering electric kettles to boil water for tea or coffee. Switching of lights (ON/OFF) will be reduced to the barest minimum as most of the lecture rooms may not be used at all, thereby saving energy.

The heat demand is more flexible than electricity demand because it does not fluctuate rapidly during the same day. The demand is more stable when a thermal storage device is used [3].

The cooling demands during the cold seasons are mostly at peaks during morning and the night while the demand is at average during the day.

V. System Energy Input (SEI) Results

Table 1 shows at a glance, the proportion of energy flow into the hub for each particular period of time. Take for instance; lesser amount of natural gas is needed for meeting the energy demands during the Winter. Here, the O.C is seen to be higher than that of Summer and the Spring because more electricity is imported from the grid to cater for the energy demands. Similarly, in order to cut costs and reduce wastages, the results of the optimisation in the above table has shown that electricity is not needed from the grid during Summer and Autumn periods. Hence, the amount of electricity generated by the CHP system at these periods will be enough to meet the required energy demands.

Table 1: Results of Optimal Inputs with O.C

	Date Used	Time of the Day	Electricity Demands	Cooling Demands	Heat Demands
CASE 1: Winter	12/12/2014	14:00-15:00	5010	1075	7310
CASE 2: Summer	24/08/2014	1:00-2:00	6164	4070	3160

From the table, it can be observed that the operational cost always increases independently with time. This can be explained since the cost of electricity is relatively high compared to the cost of natural gas. Therefore, choosing electricity over natural gas increases the operating cost. Also, changing electricity to natural gas helps to reduce the pollutants that come from the electricity production. The proportion of energy input must careful be balanced so that the high operating cost may not discourage the use of these systems for the evaluated building. For effective cost savings and meeting the energy demands, it should be noted that not all the energy converters should be put into use at all times.

VI. Conclusions

Getting electricity from the grid during the summer and autumn seasons is seen not to be economical. Similarly, the use of GB in Spring and Summer is not also necessary as the CHP produces the heat energy required. The CCHP technology is optimised and energy flow of this CCHP system together with the operating cost for each of the climate condition is investigated for further operation strategy design. The operation strategy was first designed with the aim of meeting the energy demands at low cost. The matching methodology is adopted when designing the operation strategy for the CCHP system for each seasons of the year. The performed studies prove that the inclusion of EC along with other energy devices in the hub is beneficial, as there is a possibility of further increase in the efficiency and O.C of the system. The CCHP system performs much better than the conventional SP system in all the cases examined. The case study conducted show the feasibility of the proposed operation strategies. Test results show that, with the proposed operation strategy, there are times when power is not needed to be imported from the grid. This implies that the CCHP will be fully put into use during the said period. Invariably, wastages have been blocked and cost is further reduced.

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