DISTRIBUTED GENERATION AND COGENERATION AT UNIVERSITIES

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ABSTRACT

This paper investigates the feasibility of the implementation of cogeneration at universities with distributed generation systems in South Africa. In 2006 many universities were caught off guard by the energy crisis in South Africa, particularly in the Western Cape. To ensure that research and teaching were not neglected due to the power crisis emergency, standby generators were installed at most of the universities. This cost the institutions millions of Rands. However, the real cost implication was felt when the only utility, ESKOM, applied load shedding. Over a period of one month the generators of one institution used 15 000 litres of diesel during power failures. Cogeneration methods are discussed as a means of reducing energy consumption bills. Discussions are made of topping and bottoming cycles in cogeneration methods, utilizing either steam or gas turbines or reciprocating engines. Besides cogeneration the aim of this paper is also to promote energy consumption reduction methods at universities.

1. INTRODUCTION

In the budget speech the South African Minister of Finance announced the introduction of a 2c/kWh levy on electricity produced from non-renewable sources (coal, gas and diesel). This levy will be applied from 1 September 2008 and will be in addition to the price of the current tariffs and charges [1]. Later in 2008 the government of the Republic of South Africa set a national savings target as a percentage of the national baseline electrical consumption required to be reduced to achieve a sufficient margin between demand and supply of electricity [2]. Distributed generation (DG) and cogeneration will play a significant role in the future challenge of South Africa's power and energy industries. It will help the residential, commercial and industrial sectors to become energy efficient. This will result in reduced electricity accounts and possible carbon credits according to the Kyoto protocol. The Kyoto protocol is an international agreement reached in Kyoto in 1997 to lower emissions from two groups of greenhouse gasses. The first group is carbon dioxide, methane and nitrous oxide and the second group is hydrofluorocarbon (HFCs), sulfur hexafluoride and perfluorocarbons [3]. These requirements will impact the implementation of distribution generation sources cogeneration. Distributed generation is when electricity is generated elsewhere beside the power stations of ESKOM (the only electricity utility company in South Africa). The source of the distributed generated electricity can be fossil fuel or renewable energy sources. The reliability of the electric supply is in the hands of the owner of the DG system. The peak demand can then also be reduced. If ESKOM load shedding is applied, the electric source can flawlessly be switched from the electric grid to on-site generation. Additional to that cogeneration will also reduce energy costs for supply to thermal loads. Cogeneration is when one fuel source is used to produce more than one output (electricity and shaft power). Unfortunately the high initial cost of a DG system dissuades facilities to venture in that direction. The technology of and economic motivation for DG and cogeneration at universities are discussed.

2. DG AND COGENERATION TECHNOLOGIES

DG is electricity generated independent of the national grid (from renewable energy sources to gas turbines). Cogeneration, however is an opportunity that can be exploited on and off grid. Most cogeneration systems are based on prime movers. A prime mover is a unit that generates shaft power or electricity. They are steam turbines, gas turbines or internal combustion engines.

RECIPROCATING ENGINES

More than 90% of DG use diesel powered reciprocating piston engines. These compression ignition (CI) engines turn at slower speeds and burn heavier fuels than spark ignition (SI) engines, similar to the ones used in automobiles. CI engines however are more powerful and provide more horsepower per unit of size (up to 5 000 for SI vs 50 000 HP for CI). Their efficiencies are between 20 – 40%.

GAS TURBINES

Three different category gas turbines (Utility, Mini and Micro), range from 20kVA to 150 000kVA, turn at different speeds when connected to a generator.

UTILITY GAS TURBINES

The capacity range of utility gas turbines are between 10 MVA 150 MVA. The fuel used is natural gas or diesel with an efficiency of 37%. These turbines generate 3 phase AC synchrounously, at about 1800 rpm between 4.2 to 20 kV. The DG unit costs approximately $300 per kW in 2003 [4].

MINI GAS TURBINES

Mini Gas Turbines ranges from 800 kVA to 10 000 kVA. The speed of the generator is approximately 3600 rpm and generates AC synchronously. The fuel used is also natural gas or diesel with an efficiency of 30 to 35%. The DG unit costs approximately $450 per kW in 2003 [4].

MICRO GAS TURBINES

Micro Gas Turbines have capacities from 20kVA to 750kVA. Natural gas or diesel is used with efficiencies up to 32%. These turbines run at a too high speed (70 000rpm) to generate AC synchronously. A gearbox is required to reduce the speed. This will however decrease the efficiency. They have DC outputs that are converted to AC with inverters. The DG unit costs approximately $700 per kW in 2003 [4].

GENERATORS FOR RECIPROCATING ENGINES OR GAS TURBINES

A generator is a type of rotational machine. A rotational machine can be used as either an electrical motor or generator. Four different types of generators can be used in DG units, at a specific frequency, voltage and single or polyphase alternating current, viz:

- AC Synchronous Generators
- AC Induction Generators
- DC Generators with DC/AC Inverters
- Piston Generators

WASTE HEAT RECOVERY EQUIPMENT

Waste heat is the heat dissipated in the atmosphere or to any heat sink without being beneficial to the user. Examples are flue gases, exhaust gases, heat lost in pipes. This heat can be used to generate steam for turbines or free heat of fluid streams. The most common waste heat recovery equipment are heat pipe exchangers, waste heat recovery boilers, finned tube heat exchangers, air preheaters and recuperators.

3. TOPPING AND BOTTOMING CYCLES

A topping cycle is a thermal cycle where power is produced prior to the delivery of heat to the plant or facility. An example is heat recovered from a diesel-engine generator to produce steam and hot water. A bottoming cycle is where power is produced from the recovery of heat that would have been rejected to a heat sink. An example is the generation of power using the heat from exothermic chemical processes and kilns.

A combined cycle is a combination of a topping and bottoming cycle. Power is produced in a toping cycle (for example in a gas-turbine generator). Heat from the turbine exhaust is used to produce steam, which is expanded in a steam turbine to generate more electric or shaft power. Steam can now be extracted to be used as process heat. Figure 1 shows the abovementioned cycles [3].

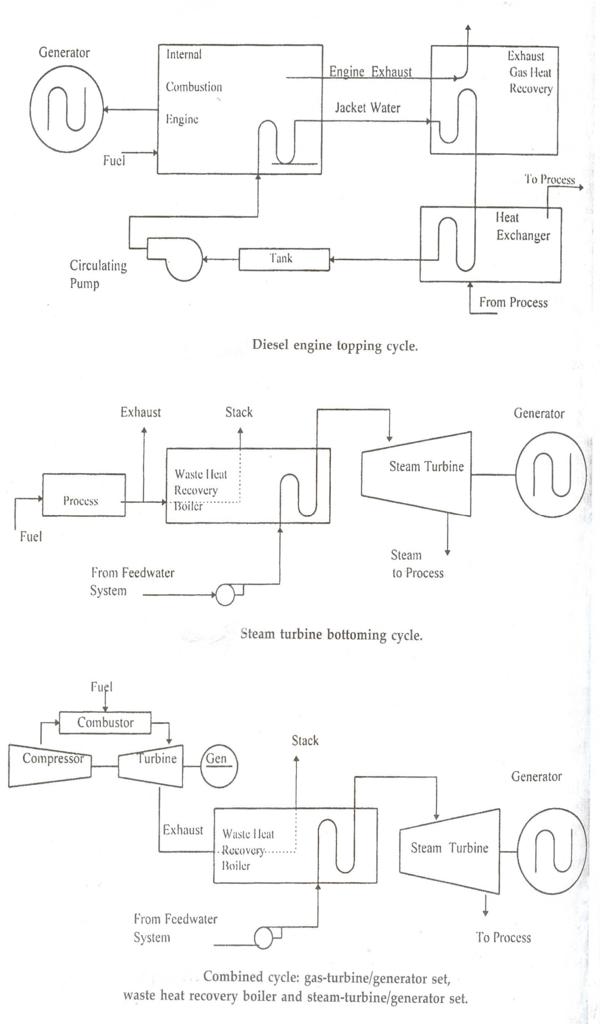

Figure 1: Examples of topping, bottoming and combined cycles

4. ELECTRICAL CONSUMPTION AT UNIVERSITIES IN SOUTH AFRICA

In 2006 many universities were caught off guard by the energy crisis in the Western Cape in South Africa. They are the Cape Peninsula University of Technology, the University of the Western Cape, The University of Cape Town and the University of Stellenbosch.

This was due to technical problems at the Koeberg nuclear power station near Cape Town. Due to the power crisis, emergency standby generators were installed at most of the universities, to minimize disruptions in class and research facilities. This was done at a very high initial capital cost. However, the real cost implication was felt when the only utility, ESKOM, applied load shedding and increased its electricity tariff.

4.1 THE CASE OF THE UNIVERSITY OF STELLENBOSCH

The University of Stellenbosch is situated about 50 km from Cape Town in the Winelands municipal area. Over a period of one month these installed generators at the University of Stellenbosch used 15 000 litres of diesel during some of the power failures. The diesel bill amounted to over R150 000 for a period just over 24 hours. In addition to the constant diesel supply, scarce manpower had to be used to refuel the generators. From July to October 2008 the electricity tariff on the main campus of the university was increased by 35%. This resulted in an annual increase of R10 million rand in their electricity bill (from R26 million to R36 million) [5]. Besides the increase by ESKOM in April 2008, a further increase of 13.3% was approved by the National Energy Regulator of South Africa (NERSA). ESKOM forecasted a further annual increase of 20% over the next three years. On top of this the university will have to save another 10% on its normal electricity consumption [2]. This is to ensure a stable supply delivered by ESKOM. If this saving cannot be achieved the university will be penalized about R10 million. The Stellenbosch municipality announced a rationing tariff of R1,50 per kWh compared to the normal bulk-user tariff of 23c per kWh, if the university exceeds a certain limit [5].

4.2 THE CASE OF THE CAPE PENINSULA UNIVERSITY OF TECHNOLOGY

The Cape Peninsula University of Technology (CPUT) has two main campuses, located in Cape Town and Bellville (centered between the University of Stellenbosch and Cape Town).

Table 1: Measured load at the CPUT Bellville Campus

SUBSTATION	P (MW)	S (MVA)	Q (Mvars)
NEW LIB,STD CNTR,AUDTRM	0.434	0.448	0.318
ABC BLDNG/IT	0.689	0.737	0.461
MSH,PHS,ICPLT,MSH	0.229	0.482	0.375
ELEC ENG,AC PLANT	0.147	0.173	0.0974
RES SUB (DEB,ANGLO,F/SQ	0.43	0.449	0.193
RES2,HEROES,POS GRAD	0.209	0.247	0.0773
SUB/S No 2	0.419	0.451	0.187
NEW TECH	0.131	0.204	0.157
CHEM ENG	0.138	0.165	0.0902
MGR KTCHN,Fd TECH,M BLK	0.748	0.0891	0.0757
IB,Edctn,MGR,Mn Gte	0.266	0.274	0.151
TABIESA ART DESIGN	0.202	0.388	0.331

Some of the mini-subs are backed up by diesel generators. To access the load the power consumption of twelve substations on site were data logged at the Bellville campus. From TABLE 1 it can be seen that the total load of the twelve substations alone amounts to more than 4 MW.

5. GENERATION PLANT DESIGN

Suppose a 50MW gas generation plant is proposed to be installed operating for 8760 hours less downtime per year. The generation plant can use bio-fuel thin gas and natural gas with a specific methane content. The percentage methane of 80% is guaranteed at specification. The generation will take place by Brayton cycle gas turbine technology.

Typical distributed system specifications for a 50MW unit is supplied in TABLE 2. The estimated gas utilization would be 18270M^3 x 8500h = 155 million cubic meters per annum.

Table 2: 50 MW Generator specification

Generator output (kW)	56770
Gen/gear efficiency	96%
Mass flow rate (kg/s)	4.407
Fuel gas consumption (89% methane)	18270 NM^3/h
Inlet fuel temp (C)	45
Fuel lower heating value (kJ/kg)	40827
Electric heat rate (kJ/(kW*h))	11410
Electrical efficiency %	31.55

A conventional power plant receiving fuel energy (F), procuring work (W) and rejecting heat (QA) to a sink at low temperature is shown in Figure 2 as a block diagram [6].

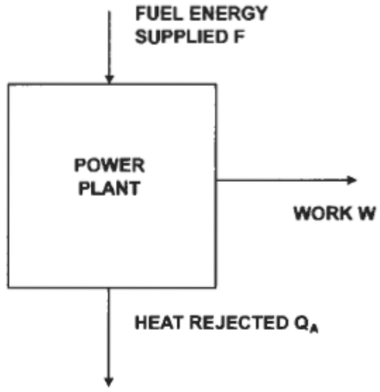

Figure 2: Plant energy, work, heat diagram

The objective is to achieve the least fuel input for a given work output as this will be economically beneficial in the operation of the power plant, thereby minimizing the fuel costs. However, the capital cost of achieving high efficiency has to be assessed and balanced against the resulting saving in fuel costs. In a closed cyclic power plant fluid passes continuously round a closed circuit. This takes place in a thermodynamic cycle in which heat

QB is received from a source at a high temperature, heat QA is rejected to a sink at a low temperature and work output (W) is delivered. This work is used to drive an electric generator as shown in Figure 3 [6].

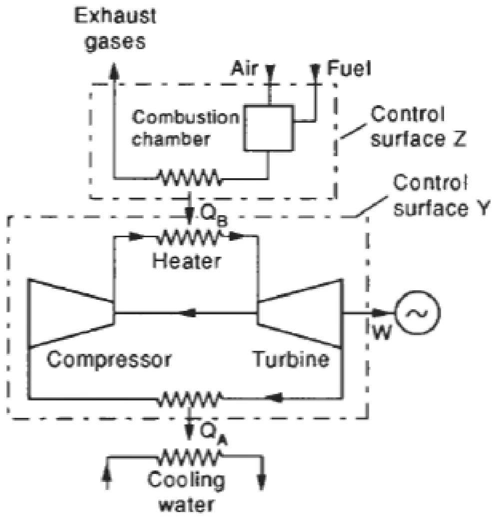

Figure 3: Closed circuit gas turbine plant

The dotted chain control surface (Y) surrounds a cyclic gas turbine power plant (or cyclic heat engine) through which air or gas circulates, and the combustion chamber is located within the second open control surface. Heat (QB) is transferred from Z to Y, and heat (QA) is rejected from Y. The two control volumes form a complete power plant. A gas turbine plant that operates on an 'open circuit', with internal combustion is shown in Figure 4 [6].

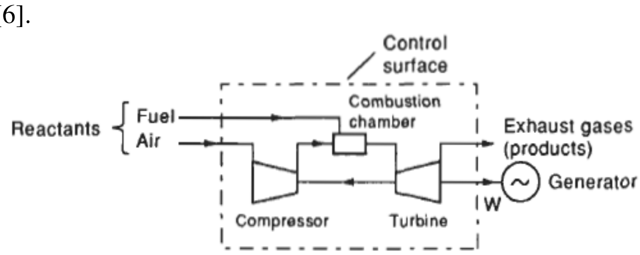

Figure 4: Open circuit gas turbine plant

Air and fuel pass across the single control surface into the compressor and combustion chamber, respectively, and the combustion products leave the control surface after expansion through the turbine. The open circuit plant cannot be said to operate on a thermodynamic cycle; however, its performance is often assessed by treating it as equivalent to a closed cyclic power plant, but care must be taken in such an approach.

Joule-Brayton (JB) constant pressure closed cycle is the basis of the cyclic gas turbine power plant, with steady flow of air (or gas) through a compressor, heater, turbine, cooler within a closed circuit. The turbine drives the compressor and a generator delivering the electrical power, heat is supplied at a constant pressure and is also rejected at constant pressure. The temperature-entropy diagram for this cycle is also shown in Figure 5 [6].

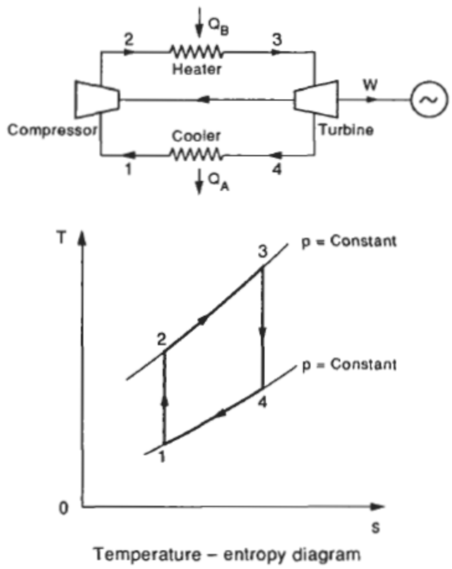

Figure 5: The Joule-Brayton Cycle

6. CONCLUSION

The impact of the electricity increase in South Africa in 2008 not only had a huge influence on the energy bill of universities but also on the economy of the country. If cogeneration in the form of a topping cycles is applied to existing, already on site installed diesel generators, then the wasted heat from the generators can be used to produce warm water during power outages. This will reduce the electricity bill for heating water tremendously. To meet the national savings target of baseline electrical consumption reduction, gas turbines can be installed and combined with steam boilers. This will result in huge electricity savings from the ESKOM grid, since the university will become less independent of the utility during power outages. These gas turbines can also use different fuel types such as methane gas with different qualities and well as diesel as a source.

7. REFERENCES

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