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Investigation of noise and environmental pollution of gas and solar cogeneration systems for use in residential buildings

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Abstract

Introduction: Non-renewable energy sources discharge destructive gases to the environment; In addition, they have restricted assets that will be depleted in the early future. In gas power generation systems, a large amount of heat is lost by exhaust gases. Consequently, using of waste heat increases power plant's efficiency. The combined cooling, heating, and power (CCHP) is a system that can produce power, heating, and cooling from a common energy source such as natural gas, oil, or sun. In a CCHP system, waste heat drives heating and cooling devices. In this paper, the amount of noise and environmental pollution of the gas CCHP system and the Solar CCHP system have been investigated and analyzed.

methods: Gas cogeneration systems have been studied in terms of pollution and noise produced for residents. Due to the multiplicity of primary actuators, only natural gas actuators that can be implemented in residential buildings are considered here. All calculations have been done for residential buildings with EES software and after analyzing the gas cogeneration system,

Results: The results have been compared with the solar cogeneration system. The initial cost of the systems, the pollution created and the amount of noise in the various prime mover of the cogeneration systems have been examined and the cogeneration system with the solar collector has been described as the cleanest, quietest and the most expensive cogeneration system.

Conclusion: It is possible to use the cogeneration cycle in all areas and in any weather conditions, while the use of the cogeneration cycle is suitable in areas with high hours of solar radiation, which is one of the weaknesses of solar systems.

1. Introduction

Scattered power plants have been considered for many countries in recent years due to their many benefits in reducing energy consumption and environmental and noise pollution. CCHP systems are one of the types of power plants. It is widely used for various industrial, commercial and residential parts. The development of distributed generation has led to significant results in reducing environmental pollution losses and transmission costs. cogeneration of electricity, heat and cold is one of the most important applications of distributed generation, which in addition to increasing efficiency and reducing fuel consumption, also reduces greenhouse gas emissions. One of the technologies used in distributed

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generation that is widely used in non-industrial applications is internal combustion engines. Internal combustion engines convert about 25 to 40 percent of the energy of the input fuel into efficient use and waste the rest of the energy of the input fuel as heat, which is a great threat to the environment by creating carbon monoxide and ambient heat. Therefore, by recovering the lost heat, internal combustion engines have a suitable potential for use in cogeneration systems, reciprocating combustion engines and gas micro turbines are used in this field(Cardona & Piacentino, 2003).

Considering the wide consumption of fossil fuels in the sector of meeting the needs of heat, refrigeration and air conditioning and its increasing development, the need to optimize this part of consumption is well felt. On the other hand, the use of cogeneration technology provides huge potential for energy savings. For this reason, the use of systems for the cogeneration production of electricity and heat in power plants with the aim of reducing energy consumption and environmental pollutants is one of the major challenges in the field of production and distribution. The use of solar cogeneration systems is also one of the important options in reducing environmental pollution, due to the production of the driving force of the system from the sun, carbon monoxide production in the solar cogeneration system reaches zero. Among the cogeneration systems, the financial debate and the initial cost are very important. CCHP is the cogeneration of mechanical power (often converted to electricity) and heating or cooling from a primary source. The heat dissipated is obtained from the CHP to generate cooling power. While the benefits of CHP go back more than 100 years and are well established, the development of CCHP is quite slow and is often limited to hybrid absorption chillers with large-scale power generation systems (until the mid-1980s)(Galanti & Massardo, 2011).

Various researchers have studied and analyzed cogeneration production cycles with respect to the reduction of fuel consumption and environmental pollutants (Wang, Jing, Zhang, & Zhai, 2011).

General specifications of the system:

In cogeneration systems with internal combustion engines, after starting the system, the generator is directly connected to the motor output shaft and supplies electricity. The energy from the combustion of engines, which is released as heat energy from the radiator and engine exhaust, is used as space heating in the boiler system or cooling energy supply in absorption chillers. For optimal use of the cogeneration system, by using the absorption refrigeration system in summer, the heat of the system is wasted in such a way that the hot water output of the system is used as the input of the refrigeration system and provides the required cold in it (Tonekaboni, Salarian, Fatahian, & Fatahian, 2015).

2. Methods

Energy efficiency calculations and relationships for the system

The most well-known energy efficiency evaluation relationships for heating and cooling systems are performance coefficient (COP), which is not a suitable and reliable criterion in cogeneration systems and can be used for stand-alone systems. The performance energy rate coefficient (PER) is introduced here for energy calculations (Lu, Li, & Xia, 2018). The lower the coefficient, the lower the energy consumption and the lower the pollution. The PER coefficient in CCHP systems is expressed as follows.

$$PER_c = \frac{Q_{pc}}{\sum Q_h + \sum Q_c + \sum Q_{hw} + \sum P_c} \quad (1)$$

For the above components we have in different seasons:

For summer:

$$\sum Q_h = 0 \ . \sum Q_c = Q_c \ . \sum Q_{hw} = Q_{hw}^{"} \ . \sum P_c = P_c \quad (2)$$

For winter:

$$\sum Q_h = Q_h \ . \sum Q_c = 0 \ . \sum Q_{hw} = Q''_{hw} \ . \sum P_c = P_c \quad (3)$$

For spring and autumn:

$$\sum Q_h = 0 \ . \sum Q_c = 0 \ . \sum Q_{hw} = Q''_{hw} + Q'_{hw} \ . \sum P_c = P_c \quad (4)$$

For an independent system, this coefficient is as follows (Yang & Zhai, 2018):

$$PER_s = \frac{Q_{ps}}{\sum Q_h + \sum Q_c + \sum Q_{hw} + \sum P_c}$$

Nomenclature:

COP: Performance coefficient

Q: Heat rate

P: electrical energy output

Q_c : Output cooling

Q_h: Output heating

Q'_{hw}: Capacity of domestic hot water production by boiler

$\sum Q_h$: Total heat output used in the CCHP system

$\sum Q_c$: Total cooling capacity of CCHP system

$\sum P_c$: Total output power of CCHP system

$\sum Q_{hw}$: Total heat capacity of domestic water consumption CCHP system

3. Results

According to the calculations and using the data in the table1, it can be concluded that the PER coefficient for the CCHP system is lower in summer than in winter. The reason for this is that in the summer months, the production of cooling by the chiller is 1.2. If the heat generation efficiency coefficient is 0.9, it means that the absorption chiller is the basic guarantee of the energy efficiency of the CCHP system(table 1).

Table1: PER values in CCHP system and distributed generation system in different seasons

title	summer	winter	Spring& autumn	Year
For the CCHP system	1.072	1.149	1.145	1.116
For standalone system with home air conditioning	1.745	1.74	1.742	1.743
For independent system with central air conditioning	1.585	1.72	1.70	1.742
CCHP system with ventilated room	0.359	0.341	0.386	0.359
CCHP system with central ventilation system	0.333	0.34	0.323	0.331

Economic analysis:

Technical and economic parameters of CCHP technology was shown in table 2.

Table2: Technical and economic parameters of CCHP technology

Parameter	unit	Sterling engine	Microturbine	internal combustion engine	Solar collector
capacity	KW	25-100	25-100	20-5000	10-1600
Electric performance	%	29-40	25-35	25-45	20-35
Noise	dB	50-75	58-83	80-100	38-42
NO_X emission	Ibs/MWh	0.4-2	0.5-2.2	2.2-2.8	0
Maintenance	$/KWh	0.004-0.015	0.002-0.01	0.007-0.015	0.002-0.008

The basic pricing factors for the economic evaluation of the CCHP system include initial investment, operating and maintenance costs, fuel price and energy price purchased, as well as the price of energy sold to the system.

$$\mathrm{AC} = \mathrm{HP} * \sum Q_h * CP * \sum Q_c * HWP * \sum Q_{hw} * EP * \sum P_c \tag{6}$$

$$\mathrm{AS} = \mathrm{AC} - \mathrm{NGP} * \sum \mathrm{NGP} - \mathrm{MC} - \mathrm{RC} \tag{7}$$

The daily and annual working hours of the cogeneration system are often considered as a critical parameter in the decision to evaluate the profitability of an investment. Another important parameter influencing the economic studies of the CCHP system is the price of fuel (natural gas) (Rostamzadeh, Ebadollahi, Ghaebi, & Shokri, 2019).

$$\mathrm{PP} = \frac{\sum \text{capital invested}}{\sum \text{project cash flows in financial period}} = \frac{\mathrm{CC}}{\mathrm{AS}} \tag{8}$$

After writing the codes in EES software, the charts are validated with reference charts. The error rate is 1.13 which is acceptable. The compatibility of the graphs is shown in the figure1.

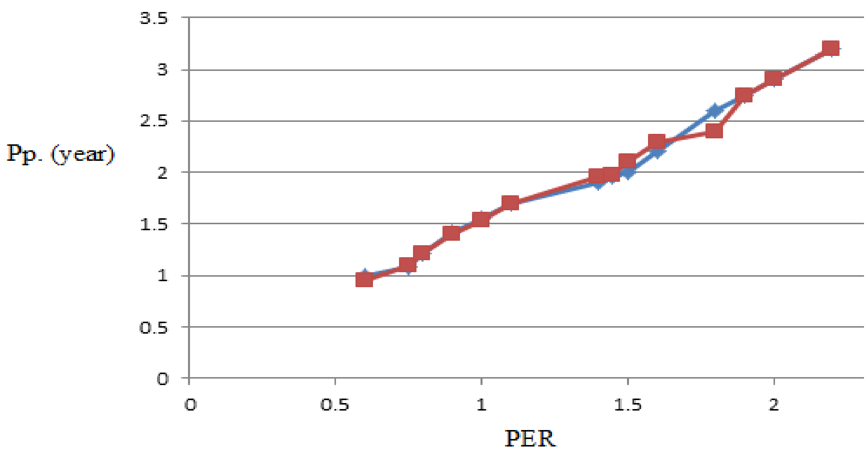

Figure1: PER coefficient compliance after coding in EES software

In this paper, the financial analysis of the system for a 4-unit building with an area of 480 meters and 2 floors, which is a 160 kW motor is used to meet the needs of electricity, cooling and heating. In this cycle, the cost of a gas engine and equipment is $ 68,500. According to the fuel consumption and the amount of energy consumed in the system, the financial return period has been calculated for three types of engines in this cycle, the financial return period is 6.2 years for the cogeneration system, 7.1 years for the Sterling engine and 8.7 years for the micro turbine. This period of financial return against the amount of financial return in production cycles simultaneously with solar energy, which is a figure equal to 14.84 years in solar cycles with parabolic collectors, and if PVT collectors are used, this period of return increases to 16.76 years. The figure 2 compares the financial return period in different cycles with different engines along with the simultaneous production cycles of the sun, which were reviewed in similar cases by Tonekaboni et al. In 2015. The table 3 shows the initial cost rate of the system and its payback period.

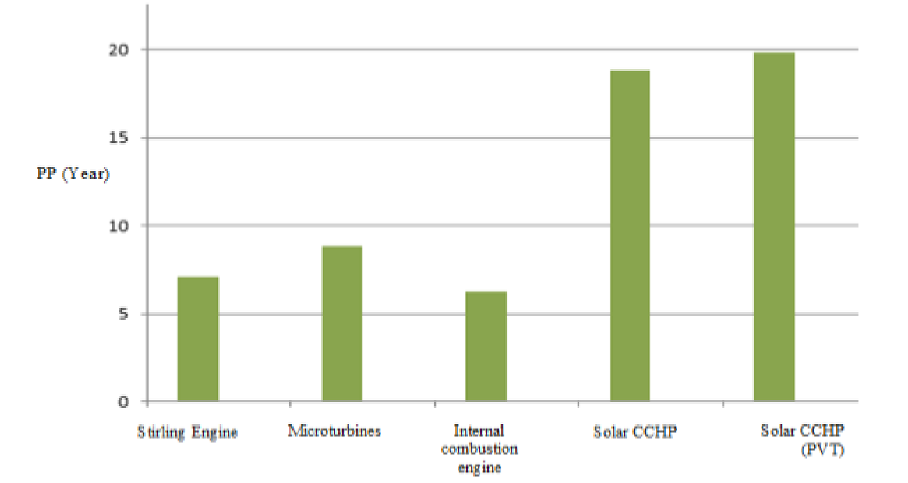

Figure 2: Display financial return time in gas and solar cogeneration cycles

Table 3: Amount of initial expenses and time of financial return on investment

propellant	Financial cost($)	Payback period (years)
internal combustion engine	68530	6.2
Sterling engine	76163	7.1
Microturbine	80665	8.7
Solar collector	108558	17.84
PVT collector	112880	18.73

4. Conclusion

In this paper, cogeneration cycle (CCHP) based on gas engine propulsion is simulated with EES software and after reviewing various systems and energy analysis, it is compared with solar cogeneration cycles based on environmental pollution and The amount of noise pollution. In this project, the production system is analyzed simultaneously with different engines and the financial return for different modes is calculated. In the simultaneous production system with internal combustion engine, the minimum initial cost of the system is estimated at $68,530 for 480 meters. The cheapest cogeneration cycle with an internal combustion engine costs $68,530 for a residential building, and the most expensive cogeneration cycle is solar with $112,880. The lowest noise output of 42 dB for the solar cogeneration cycle and the zero emission rate make this cycle the cleanest and quietest cogeneration cycle for residential buildings. The payback period is very important and if the payback period is less than 10 years, the initial investment is acceptable. The initial cost and financial return period in this system is high and this is the main reason for not using this system in residential buildings. If the cogeneration cycle is used solar energy, the financial return of the project is equal to 17.84 years, and if the cogeneration cycle is used PVT collectors, this payback period will increase by 18.73 years. It is noteworthy that in solar cogeneration cycles, the cost of fuel is zero and if needed, the electrical power of the electrical network is used. But the initial cost of running the system is more than $110,000, which makes the payback period too long. Highlights in this article are:

In the economic study of the cogeneration system, the component of primary energy rate (PER) is introduced and used instead of the component of coefficient of performance (COP). And this coefficient is lower in summer than in winter.

The most important option in choosing the primary driver is the amount of fossil fuel consumption, the lower the consumption of fossil fuels, the lower the amount of NO_X production.

Solar CCHP has the lowest amount of pollutants and noise production. For this reason, it has the most suitable option for residential buildings.

The best option in gas-fired cogeneration cycles is to use internal combustion engines, which reduces the payback period to 6.2 years.

It is possible to use the cogeneration cycle in all areas and in any weather conditions, while the use of the cogeneration cycle is suitable in areas with high hours of solar radiation, which is one of the weaknesses of solar systems.

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