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An innovative and integrated approach for using energy from the flooded coal mines for pre-warming of a gas engine in standby mode using GSHP

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Abstract

The effort to reduce energy consumption and carbon emission is driving companies to integrate multiple energy technologies to achieve the goal of reducing overall energy consumption, enhancing efficiency and decreasing operational cost. This paper outlines an innovative approach for integrating energy from flooded coal mines via a Ground Source Heat Pump (GSHP) to provide heating to buildings and at the same time to pre-warm a gas engine in standby mode. Once operational, the gas engine will produce significant waste heat that will replace the GSHP in heating the buildings. The results show that this energy integration technology provides much improved overall Coefficient of Performance and reduce carbon emission.

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Keyword: GSHP, Energy Integration, Low Carbon Technology, Gas Engines

1. Introduction

In the UK nearly half of all the energy is utilised for domestic and commercial heating and hot water requirements [1] and it costs the UK economy nearly £33 billion a year [2]. Currently only about 1 % of the heat generated is from renewable sources [3]. The UK is aiming to use renewable energy resources to provide nearly 12% of all the heating demand in the UK by the 2020 [4]. Flooded coal mines in the UK are a potential source of low enthalpy energy due to their availability all over the UK. Water from flooded coal mines is ideal to be used for heating and can greatly help in meeting the target of sourcing 12% of

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heating demands from renewable energy and reduce carbon footprint. The energy sourced from wind is not always available and difficult to predict on the long term; at the same time without energy storage, solar energy will not be available at night. As the reliance on renewable energy is increasing, it is also necessitating the need to have a backup, mainly internal combustion engine generators as they can be pressed into service quickly to meet the demand. However, gas and diesel engines, particularly in winter, require heating when they are on standby to allow rapid start and reliable operation. Figure 1 presents an example of UK electricity demand during 24 hours period on 11 January 20016, a typical winter day in the UK. The demand peaks in the afternoon between about 4 PM and 7 PM. When this peaks occurs at low wind speed, stand by gas engines will start their operation to compensate for the high demand. This paper presents a novel and new approach on how a GSHP system is be used to pre-heat a standby gas generator, so that it can be readily started as and when there is a demand for electricity owing to demand and supply mismatch from the national grid. Other advantage of this system is to partially recover the waste heat from the cooling system of the engine and use it to provide the required heating for buildings.

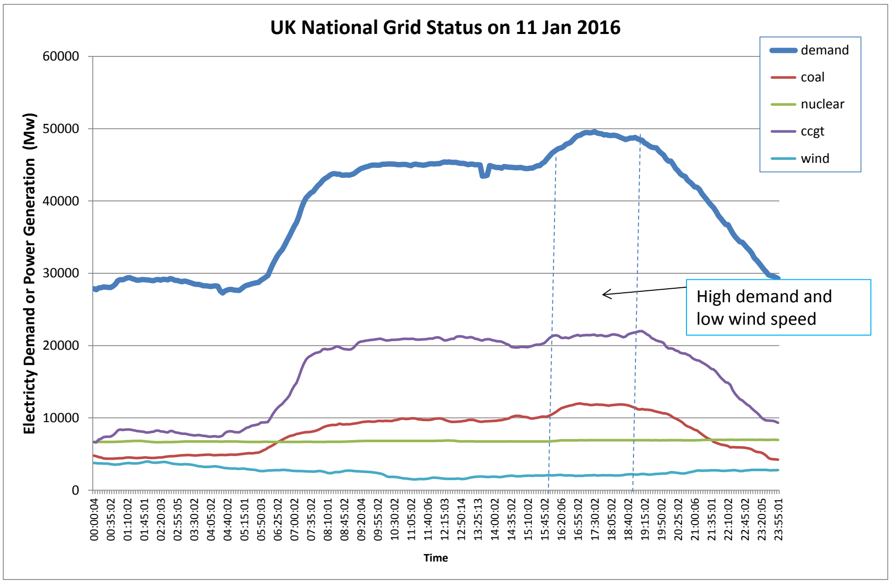


Figure 1: An example of UK electricity instantaneous demand and supply data on 11 Jan 2016, (data source: [5]).

2. Energy Recovery From Flooded Coal Mines Using Heat Pumps

There was a widespread closure of collieries in the UK and in Europe towards the end of the 20th century. When the collieries were active, and in order to safely extract coal from the underground seams, water had to be continuously pumped out. Once the mines closed the pumping operations ceased. This stoppage had led to the recovery of water level to water table level and therefore most of the mines are now flooded [6,7]. The application of mine water for heating and cooling applications has been well known for quite some time, but still not many installations have been documented, as of 2013 only 20 were documented [8].

A detailed description of heat pumps principle of operation, types and configurations has been mentioned in [9-11]. The latest trends in the heat pump technology has been also described in reference [12]. The models to estimating the amount of thermal energy that can be recovered from flooded coal mines has been described in references [13-15]. The details of the various mine water based heating and cooling installations around the world has been described in [8,16-18]. Reference [19] describes a novel simulator to teach and understand the technology in detail in a lab environment. A pilot mine water heating and cooling scheme has been successfully implemented in the Dutch town of Herleen and the details of this scheme has been described in [20, 21].

The efficiency of a heat pump is measured in terms of COP (Coefficient of Performance). It is the main parameter of interest. It is the ratio between the thermal energy output of the heat pump and the electrical energy consumed by the heat pump. The amount of energy produced and consumed by the heat pump mainly depends upon the heat transfers between the mine water and brine, brine and evaporator of the heat pump and between the condenser of the heat pump and building's heating fluid. The COP of the system is measured as a ratio of the thermal output of the system to the energy consumed by the system. This includes electricity consumed by the mine pump in addition to the heat pump. When the gas engine is in operation, there will be no need to run the heat pump and the waste heat from the engine will be used for heating the buildings.

In mathematical terms:

Energy that can be extracted from the mine water is calculated using equation 1.

$$Q_{mw} = m_{mw}.C_p.\Delta T \quad kJ \tag{1}$$

Where:

Q_{mw} is the thermal energy of mine water in kJ, m_{mw} is mass of mine water in kg, C_p is the specific heat of water (4.18 kJ/kg.K) and ΔT is the difference in temperature in Kelvin.

Efficiency or COP of the heat pump is calculated using equation 2.

$$COP_{Heatpump} = \frac{Thermal\ Energy\ produced\ by\ the\ heat\ pump\ in\ kJ}{Electrical\ Energy\ consumedby\ the\ heat\ pump\ \ in\ kJ} \tag{2}$$

$$\mathrm{COP}_{Heatpump} = \frac{Q_{HP}}{W_{HP\ electrical}} \tag{3}$$

Where
$W_{HP\ electrical}$ is the electrical power consumption of heat pump in kJ, Q_{HP} is the thermal energy output produced by the heat pump in kJ

Efficiency or COP of the system includes the energy consumed by the heat pump, mine water pump and the circulation pump and it is calculated using equation 4.

$$COP_{system} = \frac{Thermal\ Energy\ produced\ by\ system\ in\ kJ}{Electrical\ Energy\ consumed\ by\ system\ in\ kJ} \tag{4}$$

$$COP_{system} = \frac{Q_{HP}}{W_{HP\ electrical} + W_{MP\ electrical} + W_{CP\ electrical}} \tag{5}$$

The modified efficiency or COP of the system includes the energy recovered from the engine in addition to the thermal output of the heat pump and is calculated using equation 6.

$$COP_{modified} = \frac{Q_{HP} + Q_{recovered}}{W_{HP\ electrical} + W_{MP\ electrical} + W_{CP\ electrical}} \tag{6}$$

Where

$W_{CP\ electrical}$ is the electricity consumed by the circulation pumps in kJ and $Q_{recovered}$ is the thermal energy recovered from the waste heat of the engine.

3. Overall system description

The mine water heat recovery system under discussion has been used to heat the buildings described in detail in reference [22]. Figure 2 shows an image of the Markham site where the system is installed. The heating from this GSHP has been modified to pre-warm the gas engine in standby mode and then recover the waste heat from the engine when it is in operation. The overall system, see reference [22], consists of pumping the lukewarm water from the existing mine shaft of former Markham colliery and is the passed through a shell and tube heat exchanger, where a part of the energy from the incoming mine water is extracted by the cooler brine coming from heat pump. Then the cooled mine water is injected back to the coal mine, while the warmer brine is pumped back to the heat pump.

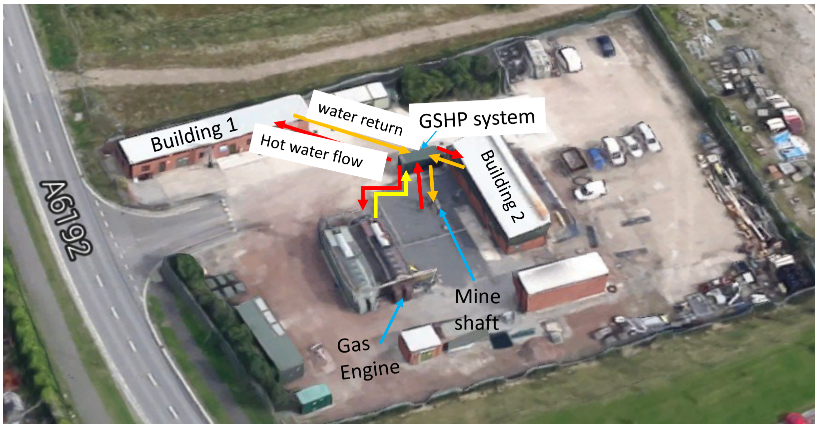


Figure 2: A satellite image of the GSHP system site (source: [23])

The heat pump in this situation upgrades the lukewarm water with its low grade energy of the brine into a more useful high temperature high grade energy; where this high temperature water is pumped into a buffer tank. The buffer tank stores the high temperature water, from where it is circulated around the building and also the engine to keep it warm and ready for operation in cold weather. The buffer tank not only ensures the supply of constant temperature water, but also prevents frequent cycling of the compressor and thereby increasing the efficiency and life of the compressor of the heat pump.

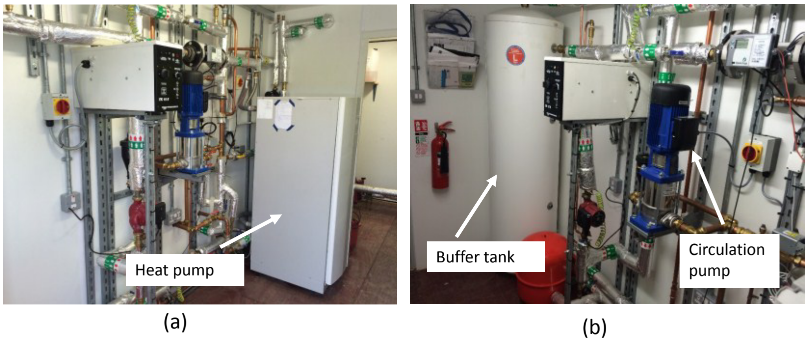


Fig. 3. A picture showing the heat pump (a), and the buffer water tank with the circulation pump (b).

Figure 3 presents the heat pump system which includes the heat pump Figure 3-a and buffer tank Figure 3-b. Further details about the system can be found in [22].

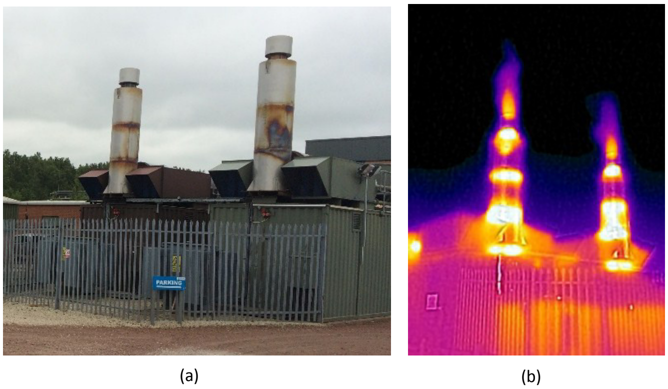
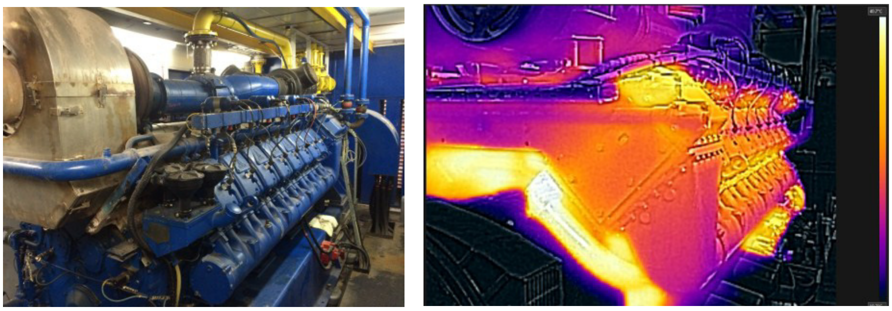


Fig. 4. The gas engines on the site (a), and the infrared image of the system showing the significant heat produced during operation (b).

Figure 4 shows two gas engines on the site. The gas engines are used as a STOR (Short Term Operating Engine) generation. Whenever there is a demand or supply mismatch, National Grid, the main electricity transmission and distribution company in UK tries to balance electricity supply and demand by procuring additional power from the independent generators such as Alkane Energy at a short notice. Alkane Energy uses gas engines to supply the additional electricity and in order to start the engine quickly, the engines have to be pre-warmed. For this innovative work, one of the engines has been linked to GSHP to improve COP and efficiency.

4. Results and Discussions

Figure 5 shows the gas engine during operation and the heat generated using an infrared image. Figure 6-a shows a schematic of the GSHP system in heating mode, where the GSHP system is heating the building and the engine in standby mode. Figure 5-b shows when the engine is running and a part of the waste heat from the engine is recovered and is stored in the buffer tank in the form of hot water, which is then circulated around the building, thereby removing the need to switch on the heat pump and mine pump, resulting in higher COP values.



(a) (b)

Fig.5. The gas engine with heating system installed (a) and infrared image of the preheated engine on stand by (b).

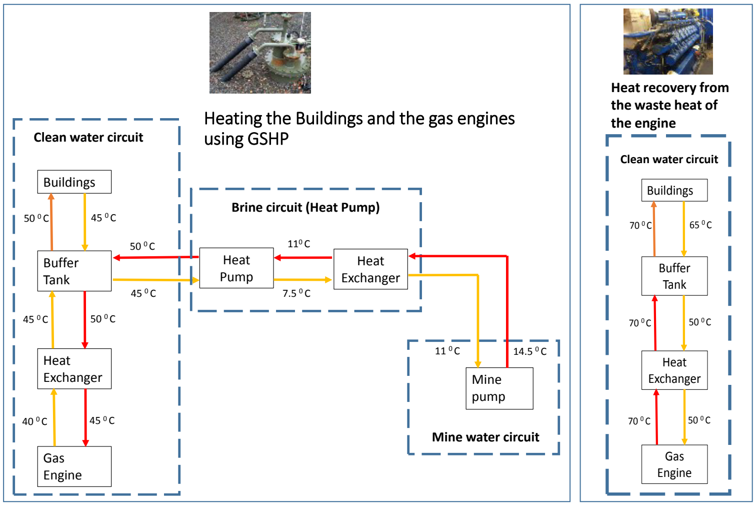


Fig. 6. A schematic block diagram of heating using GSHP (a) and a schematic block diagram of waste heat recovery (b).

During the winter period when the demand for heat is at its maximum, the gas engine runs at least for a minimum period of four hours daily. When the gas engine is running, the heat from engine's cooling jacket is used for heating the buildings. Excess heat during the engine's operation is stored in the buffer tank as hot water and this hot water is circulated around the building for heating for many hours even after the engine is switched off. Thus, removing the need to switch on the heat pump or the coal mine pump. In this case, only the circulation pumps will be needed to circulate the hot water between the building and the engine via the buffer tank. By recovering the heat from the engine's cooling jacket and using it in conjunction with the GSHP, the overall COP of the system increases by at least 25% in this case.

5. Conclusions

The global requirements to control carbon emission has led to closing down many traditional coal based power stations and replacing them with solar and wind renewable energy plants. This has necessitated the need to have a quick backup energy sources to compensate for the demand and supply fluctuations. This provides the opportunity to combine multiple technologies and thereby maximising the renewable energy produced. This paper has highlighted an innovative approach of coupling of multiple technologies together to reduce the operational costs and maximising the benefits of using more sustainable technologies. GSHP has been found useful when integrated with backup gas engines to provide an improve heating systems with reduce carbon emission and reduce cost.

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Biography

Professor Amin Al-Habaibeh is a professor of Intelligent Engineering Systems at Nottingham Trent University. He is currently the Director of the Doctoral Training Alliance for Energy (DTA-Energy) within the UK University Alliance universities. Amin is also leading the Innovative and Sustainable Built Environment Technologies research group (iSBET). Amin’s interest includes, in addition to energy, condition monitoring, intelligent systems, sustainable technologies, product design and advanced manufacturing technologies.