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Thermodynamic transient simulation of a combined heat & power system

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Abstract

In this paper a numerical model aimed at studying dynamic behavior of CHP (Combined Heat and Power) plants is presented, paying particular attention to the components in which heat transfers take place. The analysis refers to a system powered by an internal combustion engine for a compression ignition type in cogeneration configuration, equipped with two heat extractors: the first one for coolant / water, the second one for exhaust gas / water. The numerical model has been implemented by using Matlab-Simulink software. After a description of the simplifying assumptions adopted for implementing the simulator, the model is exposed in detail with regards to each single element. Then simulation results are reported for two different operating conditions aiming to assess the effectiveness of the model in analyzing the dynamic behavior of CHP plants.

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Keywords: Dynamic analisys; CHP; Cogenerator; Matlab; Simulink

1. Introduction

The CHP energy generation and, in particular, the cogeneration technique in small scale, is a technology in strong development in recent decades [1, 2]. CHP plants allow to profit from two useful effects coming from the same thermal machine: mechanical work and heat, the latter of which in the ordinary configuration would be wasted.

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The current concept of SMART GRID [3], which involves the implementation of both a thermal and electrical network with production and utilization systems located in a capillary way in the network, foresees a large use of small size CHP.

This operating mode, in small and medium scale, it is often practiced by placing heat recovery units in the two main kind of standard thermal machines such as micro gas turbines (mGT) and internal combustion engines (ICE).

The choice of the type of machine, for various reasons, is mostly directed toward the ICE [4]. These machines, when compared to the mGT, ensure:

- a smaller "scale effect", which is characteristic of all thermal engines but has less effect on the ICE, which results in greater efficiency even for small installed powers;
- ease of maintenance, as it is easier to find skilled operators for the ICEs;
- lower cost of the machine with a good effect on the payback period.

The commercial CHP-ICE size range from 35 kW_e to 10 MW_e and this kind of plants can obtain a total efficiency, inclusive of the two useful effects, up to 98%.

These machines are usually derived from diesel fuelled compression-ignition engines, but they have been recently turning into feeding by natural gas or hybrid feeding by gas and oil. The heavy duty machines for static applications are optimized to operate at constant speed of rotation: the air flow is nearly constant and the load is controlled by varying the amount of injected fuel.

Fig.1 highlights the average breakdown of primary energy into ICE. The mechanical efficiency can reach up to 30-35% while the remaining part is transferred by radiation and convection (8-10%), by the cooling system (30-35%) and by the exhaust gases (28-33%).

The software used for implementing the numerical model is Matlab-Simulink [6]. It has been chosen because its primary interface is a graphical block diagramming tool and a customizable set of block libraries, which offers tight integration with the rest of the MATLAB environment.

With this tool, it is very easy to define a set of detailed characteristic curves for each components to evaluate the behavior of the whole plant in various conditions.

2. Description of the CHP model

The simplest CHP plant (Fig.2), in which an alternative engine is employed, is composed of three main components: the ICE, a water / refrigerant heat exchanger (HEX1) and a water / exhaust gas heat exchanger (HEX2).

The component ICE will provide the mechanical work, transformed into electrical energy from the generator, and the required heat flow to the thermal users.

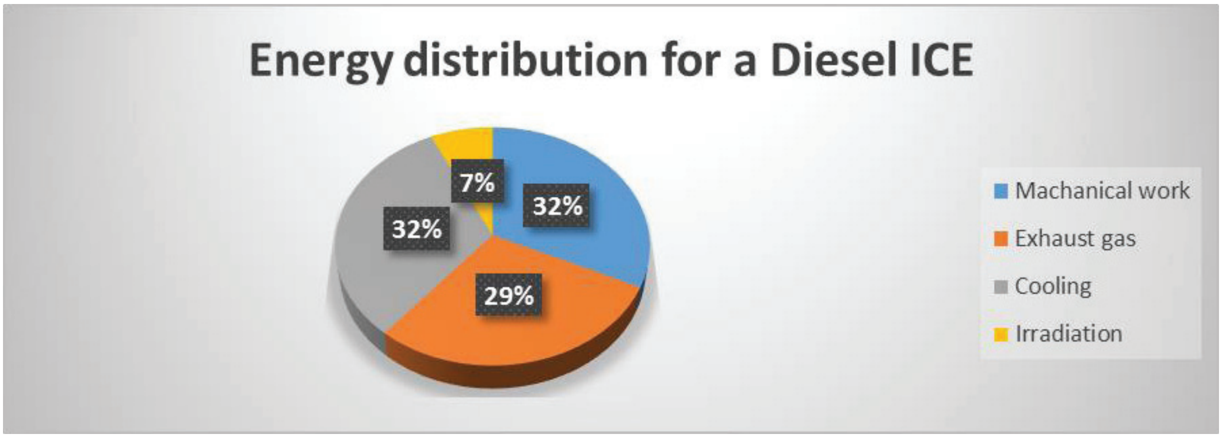

Fig.1. Mean Energy distribution for a Diesel engine (adapted from [5]).