Optimal Conception of a Hybrid Generator of Electricity

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1. Introduction

The power produced by the wind turbines is fluctuating with wind intensity. Therefore, the wind power penetration rate (WPPR - the percentage of wind power in the total power production that has to be equal to the instantaneous load) is limited on the electric distribution grid. The increase of the wind penetration rate is facilitated by the coupling of wind farms on national or regional transport grid, the use of storage systems or in the hybridization of wind turbines to the other sources of energy.
A classification of the storage techniques can be done, according to their nature of applications, into two categories [1]:

I. Techniques for large-scale storage, (pumped hydro, thermal, compressed air in cavern, flow batteries…) applied in the case of management of large electric grids to ensure the power quality control and the grid connection of different sources.

II. Techniques for average and small-scale storage, (compressed air in bottles, fuel cells, flywheel, electrochemical batteries, supercapacitor) used in the applications of weak power in remote sites and for the individual systems of electrification.

Several combinations of hybrid systems can exist: wind - diesel, wind - photovoltaic, wind – photovoltaic - diesel, wind - gas turbines, wind-compressed air and wind - compressed air - diesel. In this article we will present in detail an optimal conception of the wind - diesel hybrid system associated with a compressed air storage device.

2. Description of the system

The hybrid wind – diesel – compressed air system (WDCAS) has never made the object of a commercial application and no scientific studies are available for assessing the design and performance analysis of such a system. In this research the WDCAS is combined the diesel is turbocharged with the compressed air that has been stored. This lead to the increase of the wind energy penetration rate (WEPR) defined as the part of wind energy in the total amount of energy during a reference period, generally one year. During periods of strong wind, the surplus of the wind power (when WPPR>1) is used to compress the air via a compressor and store it. The compressed air serves then to turbo charge the diesel engine allowing to increase its power and to decrease the fuel consumption.

The figure 1 is illustrated the hybrid WDCAS system. An expander is introduced on the discharge circuit of compressed air going out of the reservoir. This will decrease the pressure of the compressed air at an acceptable level for the engine admission. At the exit of the expander, the compressed air temperature will drop significantly. Therefore it will require a preheating to avoid the frost formation, which is done by the engine exhaust gases. The pre-heated compressed air is injected into an air turbine coupled on the turbo-compressor shaft. This increase the rotation speed of the turbo-compressor, especially in the case of low regime of the engine and, consequently, the air flow supplied to the engine. This method allows the turbocharger to operate independently of the engine thanks to the energy provided by the compressed air in the air turbine.

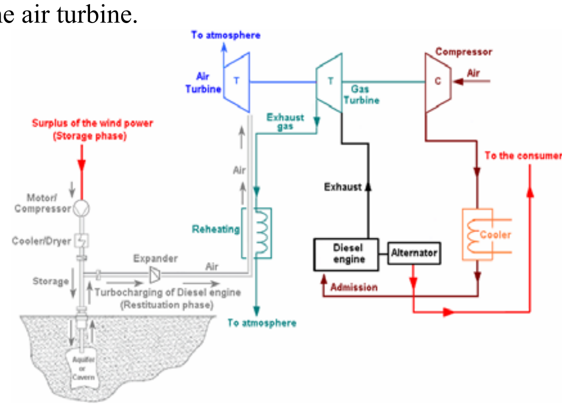

Fig. 1- Wind – Diesel – Compressed Air System

The WDCAS can be very useful for remote regions in Canada and around the world because the technology uses diesel generators already in place. Based on the available information for other compressed air energy storage (CAES) systems [2], and the analysis of the increase of the performances, we consider that on a site with good wind potential, the return on investment for such an installation is between 2 and 5 years, according to the costs of transport of the fuel. For the implementation of a comparable system in a site accessible only by helicopter, this period is less than one year [3].

3. Optimal conception

The WDCAS should provide the necessary power requested by the load by benefiting the most of the hybridization. This translates in the use the available power within both gas and air turbines to improve the filling of the Diesel engine. So, we can define the optimization problem as maximizing the compressor power as «objective function».

As any problem of optimization, a set of the constraints, defined as equalities and inequalities, must be respected. If the power of the compressor is to be maximized, it is necessary to take into account the energy balance for the engine itself and for the turbo charging system. It is also required to respect the air/fuel ratio in the Diesel, the maximum exhaust temperature, the maximum pressure of compressed air and finally, a minimum temperature of the air extracted from the storage reservoir. The problem of optimization is written as follows:

To maximize: $P_{Compressor}$

Under constraints equalities:

Engine axis: $P_{Indicated} - P_{Dissipated} - P_{Load} = 0$

Turbo axis: $P_{GazTurbine} + P_{AirTurbine} - P_{Compressor} = 0$

And constraints inequalities:

$15 < Air / Fuel < 80$

$T_{ech} < T_{limit} = 900°K$

$p_{min} \leq p_s \leq p_{max}$

$T_{detente} > T_{givre} = 223°K$

Here P, T and p represent respectively the power, the temperature and the pressure of admission. It is important to note that the validation of the equations used for the modeling of the supercharged engine constituted the object of a previous paper [4]. The results obtained by the optimization are presented in the figure 2. We note the presence of a large range of values (load varying from 1500 to 2500 Nm for a given engine). The air pressure at admission can reach in certain cases the value of 8 bars and benefit of all the advantages of the hyperbaric turbocharger [5].

4. Conclusion

A definitive conclusion requires building and testing of a prototype allowing practical validation. However, the theoretical analysis illustrates a possible application for large range of loads of this WDCAS system.

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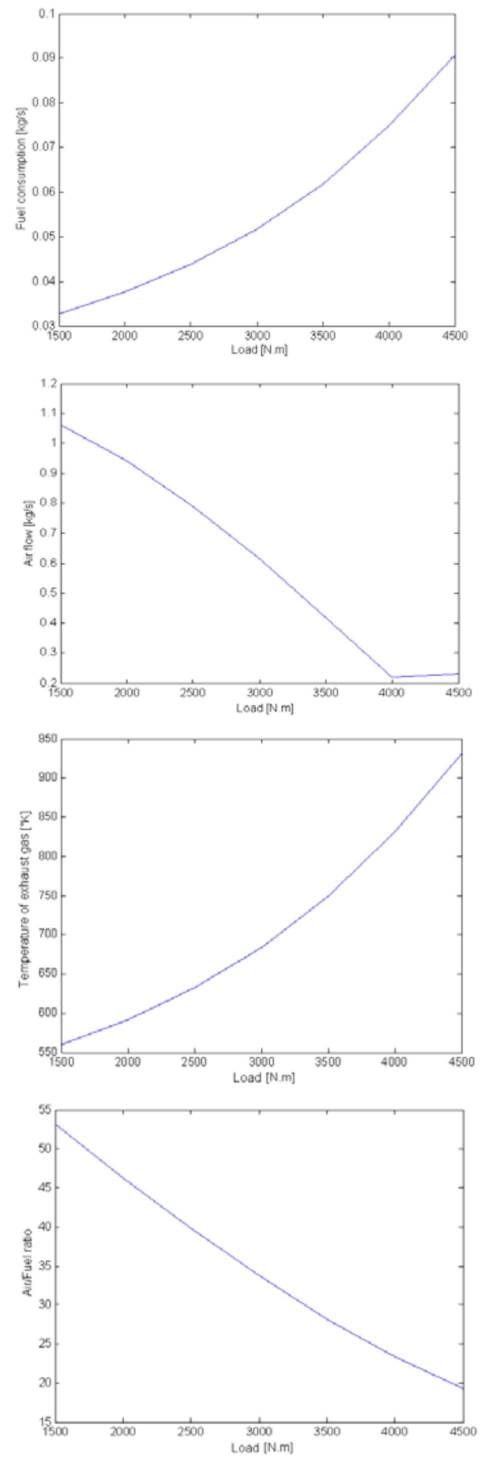

Fig. 2: 1: Injection pump rate. 2: Air flow rate at the entry of the turbine. 3: Exhaust temperature. 4: Air / Fuel ratio