

Test and simulation of an electric generator driven by a micro-turbine



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ABSTRACT

In this paper we present the results of an electromechanical design of a high speed generator directly driven by a Micro-CAES turbine, which is adapted from a turbocharger. Laboratory tests were performed using compressed air as working fluid, and with a three-phase resistive load connected to the generator. The prototype system has shown to run safely at speeds up to 100,000 rpm under no-load and up to 70,000 rpm when supplying a 3.5 kW three-phase load.

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1. Introduction

Using the same electrical machine for driving and absorbing energy has become an important alternative in the field of energy storage, mainly in technologies such as the CAES (*compressed air energy storage*) [1,2], CES (*cryogenic energy storage*) and LAES (*liquid air energy storage*) [3].

In the case of CAES, CES and LAES, the motor-compressor assembly is used to compress the fluid into a tank, converting electrical energy into thermomechanical energy. The turbine-generator assembly converts stored energy back into electrical energy, as shown in Fig. 1. During the generation process (mechanical to electric energy conversion), a vacuum is made into the compressor's side, while energy flows from the turbine to the electric generator. During the storage process the vacuum is applied at the turbine's side.

This method for energy storage is typically used in large scales power plants, such as in the ADELE project in Germany, from RWE Power Company, but is also suitable for low power and pressure systems, up to 6.0 bar, such as UPS (uninterruptible power supply) [4]. In this latter case, high speed from the rotating parts, facilitates a real fast charging and discharging process, besides of a high frequency in the electrical machine.

Although electric energy conversion at high frequencies needs less ferromagnetic and copper materials (which means lower volume), problems as vibration become challenging in this case. In addition, there are not many publications concerning energy conversion with high speed machines, see [5,6].

Some aspects of using high speed in electrical machine design are discussed by Tenconi et al. [5] and Gerada et al. [6]. However, these works present theoretical analysis and experimental evaluation without load. Fig. 2 and Table 1 present the results of output power versus angular speed using data collected from different authors. We also provide an estimated trend made from these data [7]. Although publications related with high speed electrical machines are available, there are not a study concerning the direct coupling between turbine, generator and compressor.

Kim et al. [8] present a high speed blower running up to 40,000 rpm and 8 kW, and Noguchi et al. show the efforts needed to drive a turbocharger with a high speed machine [9,10] with a rated 120,000 rpm operating system. Kolondzovski et al. also present some solutions to the difficulties of coupling a compressor propeller to a high-speed electrical machine [11].

Balancing the turbo-generator assembly is a difficult task. The challenge is due to the fact that these components should be handled as a single unit during their development. Technological aspects, such as fabrication and assembly, are barely discussed in literature, which leads to common design errors. This research clarifies some of these key points to guide future works in this theme.

This paper presents concepts and issues regarding sizing of a high speed electrical machine direct driven by a Micro-CAES

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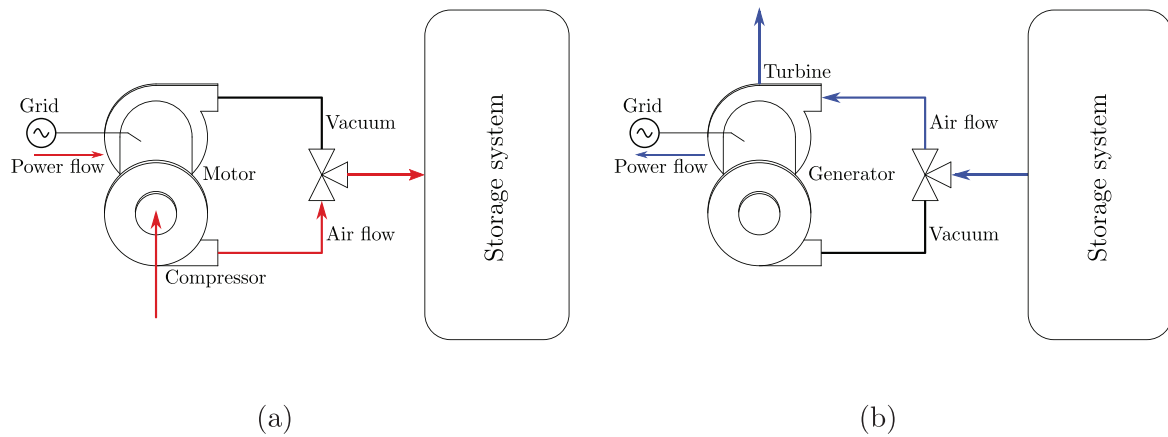


Fig. 1. Operation stages of a Micro-CAES system: (a) Storage: the electric machine drive the compressor. (b) Generation: compressed air expands in turbine which drives the generator.

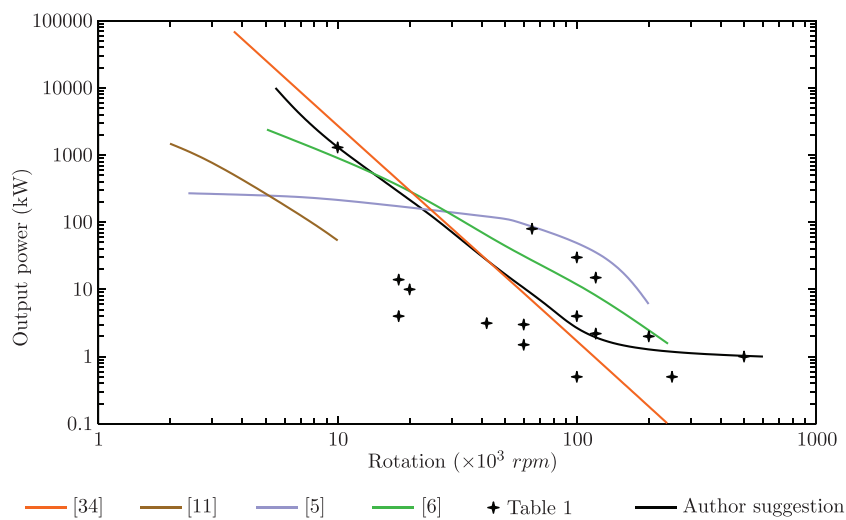


Fig. 2. State of art: high speed electrical machines.

system. The complexity is related to fabrication process and the correct topology adoption. A new sizing methodology is used and experimentally validated, where electrical machine use the kernel of turbo-machines over standard low speed electrical machines. Some essential elements allowed the electrical machine to operate above its second natural frequency, which was only possible merging works between electrical and mechanical field.

After several tests, a single shaft system associated with a high speed balancing procedure provided a successful energy conversion result. The evaluation was performed only with generation stage, but it offers enough information to validate fabrication procedures and the concordance between simulated and experimental results.

2. Micro-CAES

Micro-CAES systems are attractive alternatives to operate in grid-tie modes and with power ratings up to 100 kW. Aiming for a simple, reliable and inexpensive system, the presented turbo-compressor-generator system is based on turbochargers [2] design.

Turbochargers have been chosen as design starting point since they are world widely used in automotive industry, which make their spare parts accessible and cheap. Also, the performance map is available, which helps to choose compressor and turbine rotor.

The turbo-charger here adopted is used with Diesel truck engines and is designed to work up to 80 HP. The turbo-charger must be selected to match the operational power requests from the Micro-CAES. The electrical machine was designed according to turbo and bearing sizes, and thus merged with the system as shown in Fig. 3.

The presented drawing illustrates how the electrical machine can be incorporated within a turbo-charger. The original radial

Table 1

Publications of high speed electrical machines with experimental evidence.

Reference	Power (kW)	Speed ($\times 10^3$ rpm)
Takahashi et al., 1994 [13]	1.5	60
Sahin, 2001 [35]	10	20
Hoshino et al., 2005 [36]	80	65
Noguchi et al., 2005 / 2007 [9,10]	2.2	120
Nagorny et al., 2007 [37]	3	60
Mirzaei et al., 2008 [38]	14	18
Sivasubramaniam et al., 2009 [39]	1300	10
Pfister et al., 2010 [40]	2	200
Imoberdorf et al., 2010 [17]	1	500
Krähenbühl, 2010 [41]	0.5	250
Novák et al., 2011 [42]	3.14	42
Crescimbeni et al., 2012 [43]	4	18
Hong et al., 2012 [44]	15	120
Hong et al., 2014 [45]	0.5	100
Capstone, 2016 [46]	30	100

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