ELECTROMECHANICAL ENERGY CONVERSION AND STORAGE SYSTEMS

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REZUMAT. Lucrarea se referă la sisteme electromecanice de conversie şi stocare a energiei. Se au in vedere doar sistemele care folosesc strict conversia electromecanică a energiei, fără a considera şi alte forme de energie. Sunt punctate o serie de similitudini în cadrul problemelor abordate în cazul ambelor sensuri de transformare a energiei. Se analizează mai detaliat sistemele de generare cu stocarea bazată pe utilizarea aerului comprimat. Se prezintă pe scurt o nouă soluție în această direcție.

Cuvinte cheie: sisteme electromecanice, conversie energie, stocare energie.

ABSTRACT. The paper deals with electromechanical energy conversion systems that use the energy storage. Only electromechanical energy conversion is considered and no other form of energy is taken into account. Some similitudes in the approached problems in the both direction of the energy transformation are pointed. More detailed are analyzed the energy generation systems with storage based on compressed air. A new solution in this direction is shortly discussed.

Keywords: electromechanical systems, energy conversion, energy storage.

1. INTRODUCTION

The paper refers to the main aspects concerning the electromechanical energy conversion in both directions: from mechanical to electrical energy and vice versa – from electrical to mechanical one. The first transformation appears in the electrical drive systems [1], [2], while the second one is specific to power generation plants. For the last case, the paper considers only the plants that use just the transformation of the mechanical energy in electrical one and no other type of energy (for instance – thermal) is involved. This is the case of hydroelectric and wind power plants [3], [4], [5].

Electromechanical energy conversion can be achieved in both directions by an electrical machine that is always reversible and can operate as motor or as generator. The basic structures in these cases are:

prime mover → generator → consumer (grid)

source (grid) → motor → working machine

For the considered cases, the prime mover is a wind or hydraulic turbine. In both cases, the last element imposes the load for the conversion system.

In the most cases, the electromechanical energy conversion system (EMECS) is connected to the grid. In such situations, the proper EMECS contains only two basic elements: turbine-generator and motor- working machine, respectively. The behaviour of the system depends on the characteristics of the two basic elements. The grid imposes the voltage and the frequency in the input or in the output of the conversion system. The EMECS is not connected to the grid only for insulated applications, having a small or a medium power [6].

The best energy efficiency is achieved in all cases when it is minimized the energy consumed from the source (for electrical drives), or it is maximized the energy delivered to the consumer / grid (generation systems). A good behaviour from the energetic point of view is obtained reducing the energy losses, or choosing a convenient operation characteristic.

2. CERTAIN SIMILAR GENERAL ASPECTS

Since an electrical machine is the central element in all electromechanical energy conversion system, many common aspects occurs in the study, design and use of such systems, independent of the sense of the energy conversion. Certain will be shortly discussed in the sequel.

Mathematical modelling

Mathematical modelling of EMECS is centered on electrical machine.

There are similar models for the same type of electrical machine and only the sign of certain variables are different, depending on the operation mode (generator or motor). This fact results from the reversibility of the electrical machines. One considers in each case a mechanical equilibrium equation (between torques) and one or more electrical equilibrium (between voltages), for each winding. The mathematical model of the mechanical part (turbine and working machine, respectively) must be also introduced. The linkage with electrical machine is accomplished through torque and speed. There is also a common parameter – the moment of inertia.

For the insulated systems, the mathematical model of the third basic element has to be considered, because there are inter-influences between source and motor, or between generator and consumer.

Speed variation

The EMECSs can be with fixed or variable speed. In the first case, the system is connected to the local grid using appropriate switching schemes. The variable speed EMECSs are connected to the local grid through an electronic power converter.

The most part of the electrical drives are uncontrolled; the speed depends only on the load torque. The asynchronous cage motor is most used for these purposes. About 25% of the electrical drives are nowadays with variable speed. The aim of these systems is to ensure the needs imposed by the technological process and to improve the energy efficiency.

There are different possibilities from this point of view in the case of the electrical power plants. For instance, the wind turbine with asynchronous generator is with fixed speed, imposed by the grid frequency. The hydraulic plants with synchronous generators are wit fixed but controlled speed, in order to ensure the imposed voltage and frequency. There are also power plants with variable speed generators [7], which ensure the imposed output variables in connection with an electronic converter. This last variant is more complicated, but allows improving the efficiency.

Energetic aspects

The above mentioned aspects indicated that the controlled EMECSs have advantages from the energetic point of view [2]. The main ways used for a convenient energetic operation are indicated in the sequel.

(a) An adequate use of the characteristics of the machines involved in the energy conversion process. In this respect, one can mention:

- the MPPT (maximum power point tracking) method for the generation plants: in this case, certain variables are chosen so that a maximal power is obtained for a given value of the flow which traverses the turbine [4], [8] and [9].

- the use of variable speed drives instead of constant speed ones, in order to obtain a desired flow (for instance, for pumps, funs etc.) [2], [10].

(b) The steady state optimization in order to minimize the energy losses; the most part of the methods are based on a flux weakening control or on an equivalent procedure [10].

(c) The dynamic optimization for the transient states: this is useful for the systems with frequently change of speed, such as wind power station or certain electrical drives [11], [12].

It should be noted that the performance index in the steady state problems refers to the power consumption/loses, while this index refers to the energy consumption/losses in the dynamic optimization problems. The both problems are efficient especially for the situations when the system has small or medium loads.

3. ENERGY STORAGE

In many cases, the electromechanical energy conversion is associated with the energy storage. Usually, the drive systems consume the energy in accordance with the needs, so that the storage of the energy is not necessary. Only in certain applications is stored the kinetic energy in flywheels [2].

The situation is not the same in the case of the generation systems, because the needs of the consumers are not always in concordance with the possibilities of the power stations.

A possibility for storage appears when there is a surplus of energy in the grid and it is used for storage and reuse of energy in the periods with high demands from consumers. For instance, the water is pumped to high level in the night and it is used in hydroenergetic plant in the day. The procedure is not efficient from energetic point of view, but can be economically viable, because of different fare of energy in the mentioned periods. The solution is used in some hydroelectric power stations (for example, Yanbaru – Japan, Dinorwig – Wales, Bath County – Virginia).

But proper energy storage must be considered only if the storage is not based on energy from the grid, which already was obtained in a power plant, but it is based on the direct conversion of a renewable energy, like solar or wind. The energy storage is used in big hydroelectric power stations in the manner mentioned above, but one can use other possibilities (for instance, batteries) for small insulated hydroelectric stations.

The energy storage is specific and necessary if the generation is based on fluctuant renewable resources.

The case of wind power stations will be discussed in the sequel.

There are many known procedures of storage as potential energy, such as those based on the use of batteries, supercapacitors, fuel cells, hydrogen cells, or using mechanical or hydraulic systems, the heating storage, the compressed air and others, or the storage in kinetic energy (as flywheels) [13] – [16]. A part of the mentioned procedures offers solutions for energy storage for a short time (for instance, less then 10 minutes), while other ones ensure the storage for a longer time. Each of the indicated procedures has advantages for certain applications.

A wind power station with energy storage has mainly two subsystems: one for conversion of the wind energy in electrical one (the main subsystem) and a (secondary) subsystem for achievement of energy storage. These subsystems interfere through energetic transfers between them. They can contain common elements, which can be eventually used with adequate commutations. Each subsystem contains several machines which transform the energy. The number of the used machines must be small, in order to reduce the cost and to increase the efficiency. The common use of certain machines reduces the costs but can diminish the flexibility.

Since the paper deals only with the electromechanical energy conversion, just conversion of the same type for storage will be discussed. Therefore, the conversion based on compressed air will be approached in the following [17],...,[23].

4. SOLUTIONS FOR WIND STATIONS WITH COMPRESSED AIR STORAGE

General aspects

A short survey of the proposed solutions for Aeolian energy conversion systems with compressed air storage is presented in [21]. In this paper it is mentioned that the problem is old (since 1885), but the number of papers and patents significantly increased after 1970.

A simple structure for wind energy conversion system (WECS) with compressed air storage (CAS) is indicated in Fig.1. The main conversion subsystem is represented in the upper part of the drawing and contains a wind turbine T1, a generator G1 and eventually an electronic converter (EC1). The energy transfer is represented with arrows (we – wind energy, ke - kinetic energy of a mechanical axis, ee- electrical energy). The local grid LG can be connected to a local consumer or to the public grid.

The storage subsystem is represented in the bottom of the drawing and contains two chains of energy conversion: one is for energy storage and other is for energy utilization. The reservoir R is a common element of the two chains and it ensures the energy storage as potential energy (pe). There are different proposed solutions for each of these channels and different interconnections with the generation subsystem. Besides the reservoir, the first chain contains at least a compressor Cp and a prime mover. This last element can be a wind turbine T2 (in some cases, it is the same with T1).

The inflow and outflow of the reservoir correspond to the air kinetic energy (ake). The second chain of the storage subsystem contains al least a turbine T2s, a generator G2 and eventually an electronic converter EC2. These ones can be the same with T1, G1 and EC1 in some cases. This supposes a convenient placement of the turbine T1, so that it can receive the kinetic energy of the air flow from the reservoir.

The conversion and the storage subsystems in the structure presented in Fig.1 are independent, they being connected only in the output. But the most part of the proposed solution uses supplementary interconnections. This fact implies to transfer the energy (of course, of the same type) between the elements of the two subsystems. Moreover, in many cases some elements are used in both subsystems. In these cases, the structure drawing in Fig 1 must be completed with supplementary elements and linkages.

The paper considers in the sequel only an independent structure [22], [23], because it has some advantages in design (each subsystem can be dimensioned in concordance with the needs), in operation (it is more flexible) and in costs. Moreover, the solution proposed in [23] allows to place all machines at the ground level. For this aim it is used a collector-concentrator, which allow the change of the direction of the air flow. In this case, it is possible to use the compressed air from the reservoir in the turbine T1. In this case, the connection between the two subsystems is accomplished through a pneumatic grid.

However, we shall not discuss this possibility and we shall have in view only the solution presented in Fig.1. Several such WECS with CAS can be interconnected through an electrical local grid. There is also the variant with a separate farm of WECSs and farm of CASs, being interconnected to the local grid.

Control of WECS with CAS

The specific problem of the control of WECS with CAS is the balance between the energy in the generation subsystem (EGS) and the energy in the storage subsystem (ESS). This balance refers firstly to the input energy: the ratio between the wind energy used for generation and for storage, respectively. The balance refers also to the output energy: one has to establish when it is necessary to reuse the stored energy and the quantity. The criteria for control of these

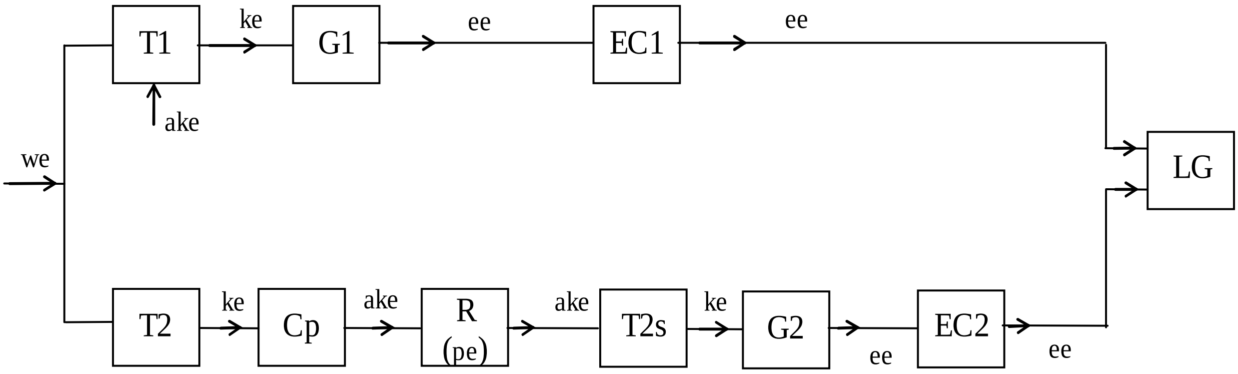

Fig. 1. Structure of wind energy conversion system with compressed air storage

balances can be different, depending on the concrete application and needs.

The mentioned balance have to be accomplished in addition to the usual control problems of WECS, like the limitation of the speed, the blocking of turbine at the excessive wind velocity and the orientation of the wind turbine. Supplementary, for the variable speed WECS, it is imposed to ensure the control of the speed or torque. An electronic power converter must be introduced in this last case. The main advantage is that one can establish the variables so that to obtain a high efficiency of WECS. In this respect, it is possible to approach an optimal control, among which the maximum power point tracking (MPPT) method is frequently considered.

In comparison with the usual WECS, the Aeolian power stations with compressed air storage in the variant with common pneumatic grid [23] offer an additional possibility to control the generator: to introduce a supplementary air flow towards the turbine which drives the generator. In this case, the balance between WECS and CAS is ensured by controller, which positions the valves that control the air flows from the two subsystems

The proposed WECS with CAS indicated in Fig. 1 can be used as generation and storage system using a common collector-concentrator, or only as storage system in combination with a usual wind turbine power station. The coupling of the two systems is achieved between the generators or between the electronic power converters. The control of a farm with several power stations implies a hierarchical structure, which is indicated in Fig. 2. The generation and the storage systems are controlled by coordinator. Each system can contain one or more energy generation subsystems (EGS) and one or more energy storage subsystems (ESS). This independent structure of the conversion system and the hierarchical structure of the control system ensure a high level of flexibility in design and operation.

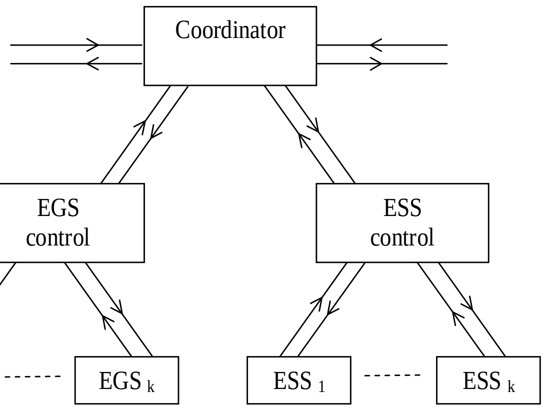

Fig. 2. Control structure for generation and storage stations

5. CONCLUSIONS

An overview of the electromechanical energy conversion systems is presented. Some similarities of the conversion in both directions are pointed.

These similarities derive from the reversibility of the phenomena and of the electrical machines.

Certain problems referring to the decrease of losses in electromechanical energy conversion are discussed.

The main aspects of the energy storage in correlation with the electromechanical energy conversion are discussed.

As a case presentation, a solution for the wind energy conversion with compressed air storage and some advantages of the proposed structure is shortly indicated.

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