COMPARISON BETWEEN DIFFERENT FLYWHEEL CONFIGURATIONS IN ISOLATED WIND PLANTS

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ABSTRACT: Flywheels are typically used as storage elements in isolated wind plants, especially those running at almost constant speed, connected to synchronous generators and diesel engines. Nowadays, systems with variable speed are under development, so the amount of available energy in the flywheel is highly increased. In this paper a comparison between an almost constant speed system and variable speed ones is presented. For variable speed, a well-known configuration based on power electronic converter with asynchronous machine is analysed. Furthermore, a novel system based on hydrostatic transmission with synchronous generator is also studied. A simulation against wind and load variations has been done in order to compare the behaviour of the different alternatives.

1. INTRODUCTION

Power systems based on renewable sources are affected by fluctuations in the generation side due to the seasonal and random nature of the source. At the same time, the load also has a variable power demand. In this case, energy storage systems (batteries, flywheels and so on) play an important role to match up generation and demand [8,11,14].

Flywheels are a popular energy storage system in the short and medium term (from seconds to minutes) in wind plants. A flywheel coupled to a synchronous generator (SG) running at an almost constant speed (less than 5% variation) form the simplest configuration [5,6,7]. This set can be driven by a diesel engine through a clutch (see Fig. 1).

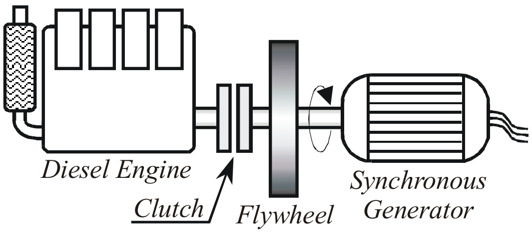

Fig. 1. Flywheel connected to a synchronous generator and diesel engine

In an almost constant speed configuration, only a small part of the energy stored in a flywheel can be extracted. A deviation of the speed from the nominal one means the same deviation in the isolated-network frequency. So, to keep the quality of power within acceptable levels, the maximum deviation must be limited. For example, for an allowable 1% deviation in speed and frequency only 4% of energy stored in the flywheel can be extracted.

In order to improve the amount of available energy variable speed flywheels can be used. Usually, in systems of this kind the flywheel is coupled to an electric machine that delivers power to the network through an electronic converter (Fig. 2) [2,11,14]. Asynchronous, switched reluctance and permanent magnet are some of the generators used in these applications [1]. Nowadays, light and high-speed flywheels are under development [4].

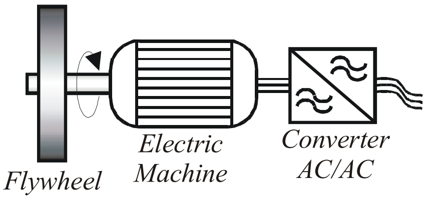

Fig. 2. Variable speed flywheel with electronic converter

In this paper a configuration that uses a hydrostatic transmission (HT) for power transmission between a flywheel and a SG is presented (Fig. 3) [12]. In this system, the flywheel speed can be greatly changed whereas the SG can run at an almost constant speed. This behaviour is achieved by means of HT that allows energy transference between systems rotating at different speeds. The robustness and the fact that this is a well-known technology are its main advantages, especially in remote plants [2].

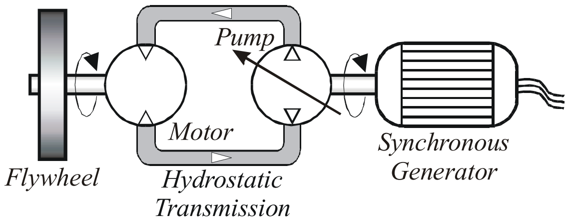

Fig. 3. Variable speed flywheel with hydrostatic transmission

A comparison between an almost constant speed flywheel, a variable speed flywheel with electronic converter and a variable speed flywheel with HT is made in order to validate the proposed system. All the systems are included in a wind energy plant where their effectiveness is evaluated.

2. ALMOST CONSTANT SPEED FLYWHEEL WITH SYNCHRONOUS GENERATOR

An almost constant speed flywheel is usually connected to a synchronous machine whose speed and frequency are directly related. This is why only small variations in speed are allowed, and only a small amount of the stored energy is available.

An example of a wind plant with an almost constant flywheel is shown in Fig. 4. A flywheel in conjunction with dump loads are the elements that maintain the plant stability, i.e., keep the frequency within limits, e.g. 50Hz ±1% [5,6,7].

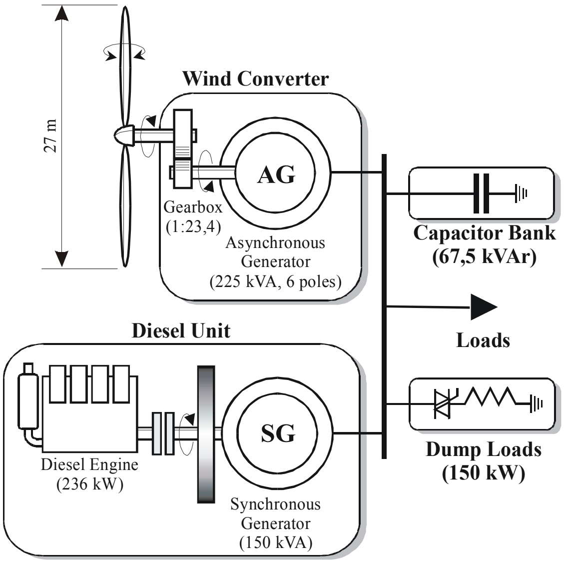

Fig. 4: Wind-Diesel plant with almost constant flywheel

3. VARIABLE SPEED FLYWHEEL WITH ASYNCHRONOUS GENERATOR AND AC/AC CONVERTER

In order to improve the amount of available energy, variable speed configurations are needed. The configuration depicted in this paper is formed by a flywheel coupled to an asynchronous generator (AG) that delivers energy through an AC/AC converter (see Fig. 2) [1].

This storage system has been included in the wind plant shown in Fig. 4 resulting in the plant shown in Fig. 5 [2].

The energy available has been dramatically raised, e.g., with a 1:3 speed variation ($\omega_{min}/\omega_{max} = 1/3$) the amount of available energy is 90% (see Fig. 6). One limitation for speed variation is torque. When a flywheel is delivering (or storing) the nominal power at low speeds, the torque will be much higher than its nominal value ($T/T_{nom}>>1$) (see Fig. 6), so mechanical parts must be oversized to manage this situation and/or a limit to the managed power as a function of speed must be applied [11].

4. VARIABLE SPEED FLYWHEEL WITH SYNCHRONOUS GENERATOR AND HYDROSTATIC TRANSMISSION

4.1. Hydrostatic Transmission

The major characteristic of HT is the ability to allow the energy transference between two systems rotating at different speeds. The main elements of an HT (see Fig. 7) are a Variable Displacement Pump, a Fixed Displacement Motor and the conducts between them (Pressure Lines) [12]. An Electrohydraulic Stroke Control is used to control the pump displacement. In this way, a wide range of speeds can be obtained in the motor shaft; meanwhile pump speed can be maintained at a reference valve by acting on the Electrohydraulic Stroke Control [3].

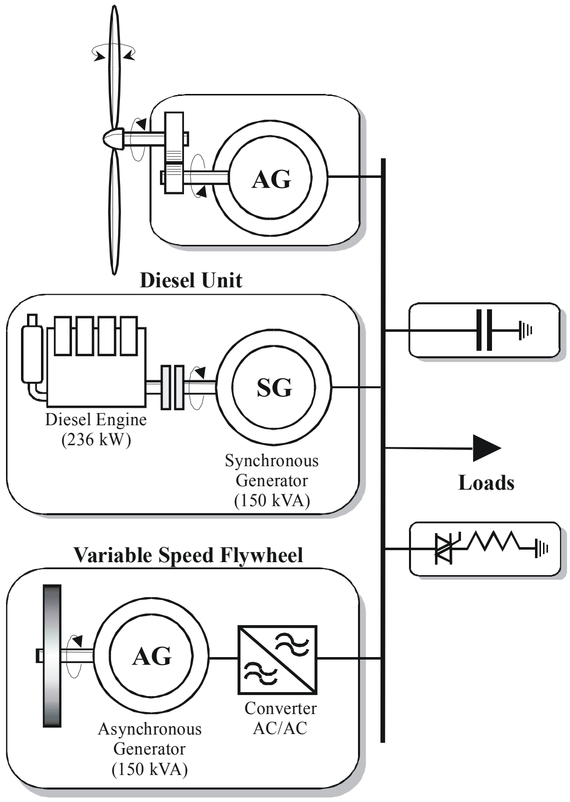

Fig. 5: Wind plant with a variable speed flywheel

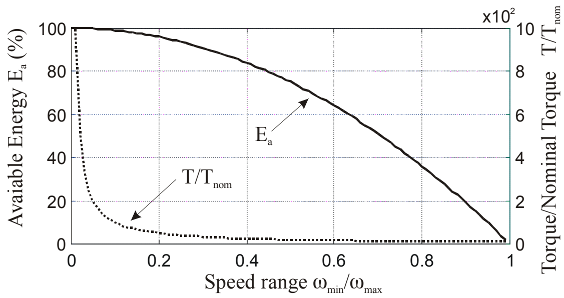

Fig. 6: Available energy (E_a) and torque (T/T_{nom}) versus speed variation range ($\omega_{min}/\omega_{max}$) when the nominal power is delivered

One of the main advantages of HT is its robustness against torque variations, since the speed of motor and pump remains almost constant during the steady state. This means that these variations are mainly reflected in the pressure. However, during the transient period, the hydrostatics fluid acts as a spring and the speed oscillates around its final value. The controller design and servovalve dynamic characteristic must be able to manage these oscillations [3].

Another important characteristic is efficiency, because the

HT has values below 70%, especially when the system is not running under nominal conditions.

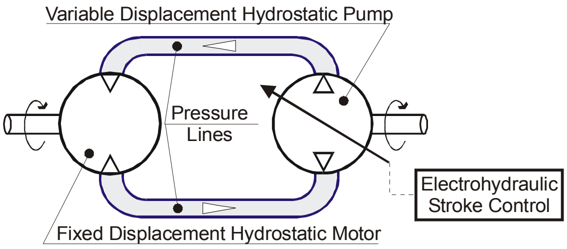

Fig. 7: Main HT elements

4.2. Storage System based on HT

Now the HT has been described, the storage system can be introduced. The proposed configuration is formed by an SG connected to a flywheel by means of an HT (see Fig. 3). The control strategy for this system is to keep the SG speed at synchronous value; meanwhile, the flywheel speed varies in order to compensate the energy balance in the system. This is obtained by acting on electrohydraulic stroke control [2,3]. An example of a wind plant with an energy storage system based on flywheel and HT is shown in Fig. 8 [2].

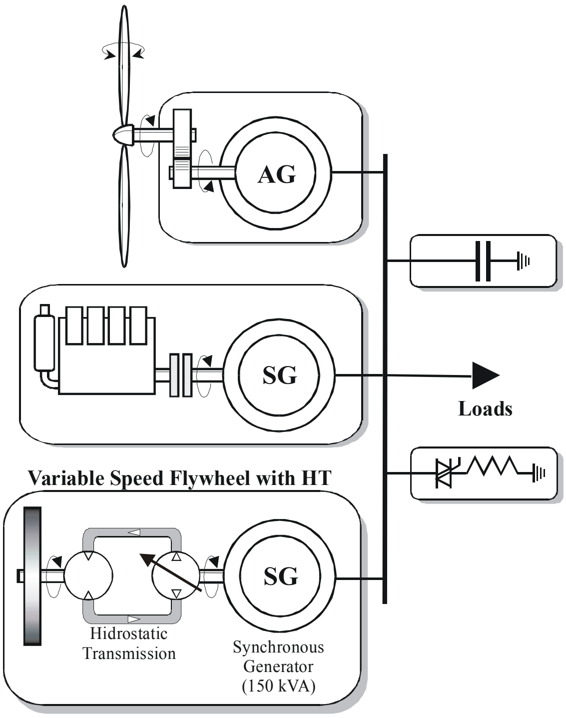

Fig. 8: Wind plant with a variable speed flywheel based on HT

5. COMPARISON BETWEEN DIFFERENT FLYWHEEL CONFIGURATIONS

In this section the results of simulation of the three isolated wind plants depicted above are shown (Fig. 4, Fig. 5 and Fig. 8). These systems are studied under two different kinds of perturbations: wind speed and electric load variations (see Fig. 9).

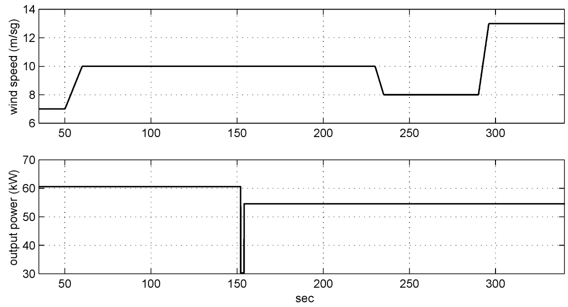

Fig. 9: Wind speed and load conditions during the simulation

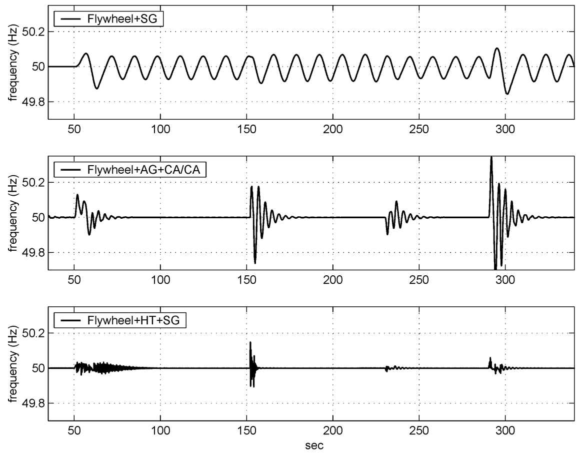

Fig. 10: Frequency in the isolated network

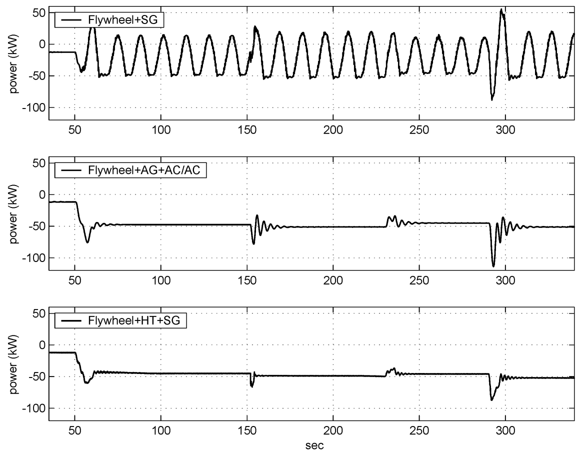

Fig. 11: Power consumption in the storage system

In Fig. 10 and Fig. 11 the results of simulations are shown, and the name for each system is:

- *Flywheel+SG*: formed by a synchronous generator (SG) and the flywheel (see Fig. 1), which rotates at almost constant speed.
- *Flywheel+AG+AC/AC*: formed by a flywheel connected to an asynchronous generator (AG) and electronic AC/AC converter (see Fig. 2).
- *Flywheel+HT+SG*: formed by a flywheel connected to a synchronous generator (SG) by means of a hydrostatic transmission (HT) (see Fig. 3).

The frequency of the isolated network (Fig. 10) and the power demand in the storage system (Fig. 11) have been chosen to compare the behaviour of the different configurations.

The frequency can be considered as quality indicator for the energy delivered by the wind plant. Taking this into account, variable speed configurations have the best response.

Nevertheless, against load variations (t ≈ 150 s) the response of variable speed storage systems is worse than the almost constant one. This is due to the fact that in variable speed systems the response against load variations depends heavily on the ability of the controller to manage it.

The amount of energy transferred between the storage system and the rest of the plant can be seen in Fig. 11. Another consequence is that in variable speed configurations the use of dump loads is greatly reduced due to the extra storage capacity.

The response of the storage system based on AC/AC converter and HT are very similar. However, this last system is based on a mechanical system which is more robust, and could be more interesting in remote applications.

6. CONCLUSIONS

Different storage configurations based on flywheels have been studied in this paper: an almost constant speed one and two variable speed ones. The main difference between them is the amount of available energy in the flywheel.

The variable speed configurations have a more appropriate behaviour against wind speed variations, however, against load variations the almost constant configuration has the better response.

Storage systems based on HT, whose response is very close to the one based on AC/AC converter, are introduced. Systems based on HT are more robust but systems based on AC/AC converter have better efficiency.

7. REFERENCES

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