An Electrical Approach to Mechanical Effort Reduction in Wind Energy Conversion Systems

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***Abstract*—A strategy for controlling wind farms composed of variable-speed machines is considered in this paper. It is shown that mechanical efforts produced by wind gusts on individual machines can be reduced by means of a supplementary control signal coming from a centralized controller. This is done while the total wind farm power output is kept at the same value as in the absence of the proposed controller.**

***Index Terms*—Torsional and flection efforts, variable-speed generator, wind energy conversion system, wind farm.**

I. Introduction

Several variable-speed generator (VSG) based wind energy conversion systems (WECS) are being currently installed [1]. There are many works dealing with the control of these kinds of machines [2], showing that both the active and reactive power outputs can be controlled in a fast, decoupled, and precise manner. By actuating upon the active power, the electromagnetic torque applied to the machine rotor can be controlled. This rotor is connected through a shaft to the rest of the mechanical system. Then, by adjusting the torque, the mechanical efforts can be diminished. These efforts are flection and torsional moments for the blades and shafts, respectively. Typically, the efforts can be generated by sudden changes of wind speed as in the case of wind gusts.

II. Model

It is considered that the electrical machine is already equipped with a controller that is capable of tracking active and reactive power references. In this paper, a simplified dynamic model, represented by the first-order transfer function shown in Fig. 1, is considered for this controller.

Regarding the mechanical components, a six-mass model is considered in order to explicitly take into account as many efforts as possible, and also to make sure that when decreasing the main source of mechanical stress, other torques are not increased. A scheme of this model is shown in Fig. 2, while the respective equations and parameters can be found in [3].

It is considered that the active power reference to be tracked by the electrical machine's controller is composed of two signals. One signal, denoted by p in Fig. 1, is generated by a proportional-integral (PI) controller in order to achieve a desired rotor speed. The other signal, termed p_s, is added to p and used transiently to decrease the mechanical efforts.

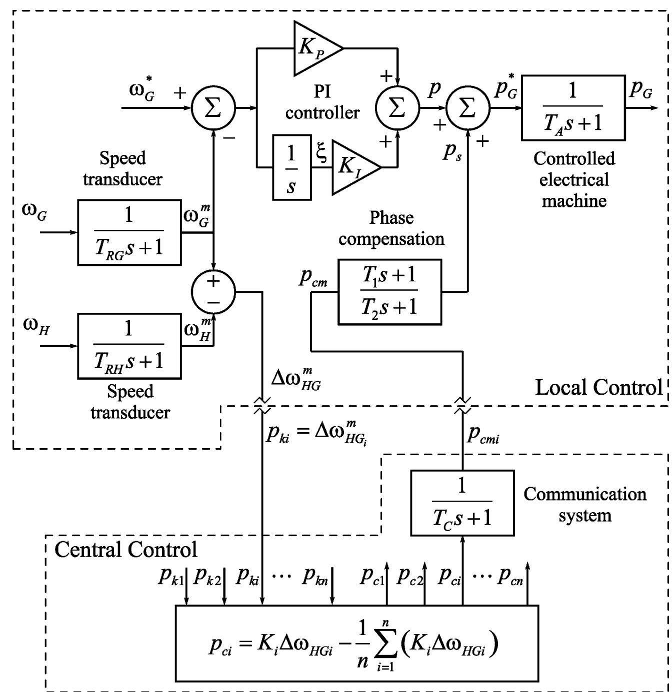

Fig. 1. Electrical machine and controllers structure.

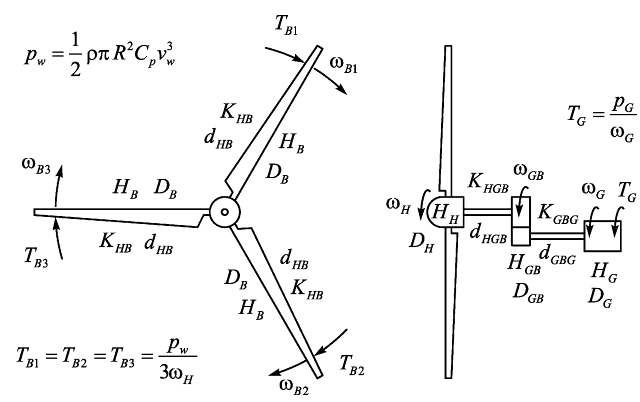

Fig. 2. Mechanical system, six-mass model.

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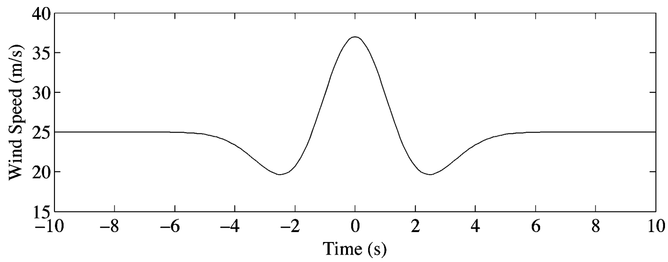

Fig. 3. Wind gust according to the IEC.

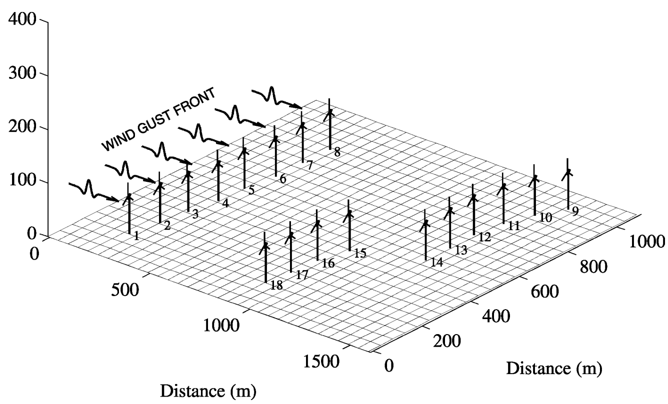

Fig. 4. Wind farm example and coming gust.

In order to apply the controller, the speeds of both the electrical machine rotor ω_G and hub ω_H are required. A delay for these measurements is considered and modeled as first-order transfer functions (see Fig. 1).

The gust model considered is as in [4], which is the same as in the International Electrotechnical Commission (IEC) 61400-1 standard about safety requirements for WECS. At a given point of the wind farm, the wind speed varies as a function of time, as shown in Fig. 3.

III. Proposed Controller

When the wind speed suddenly increases, the turbine torque rises accordingly. This torque in turn generates efforts that propagate through the mechanical system elements. If no care or special measures are exercised, the electromagnetical torque will take some time to change, because the PI loop is relatively slow. The idea proposed in this paper is to change this torque in a fast manner through the auxiliary signal p_s in order to relieve the resulting efforts to a certain extent.

The proposed strategy should satisfy two targets: 1) to reduce the mechanical efforts and 2) to maintain the same power output as if the proposed controller were not applied. In order to achieve this goal, each machine generates a signal given by

$$p_{ki} = K_i(\omega_{Hi} - \omega_{Gi})$$

which is transmitted from the WECS to the central controller, shown at the bottom of Fig. 1. This central controller generates a signal p_{ci} for each machine, which is the difference between p_{ki} and the average of all received signals. The signal p_{ci}, after the respective communication delay, is passed through a phase compensator in order to compensate for the delays considered. Finally, the desired signal p_{si} is obtained and added to the PI's reference power.

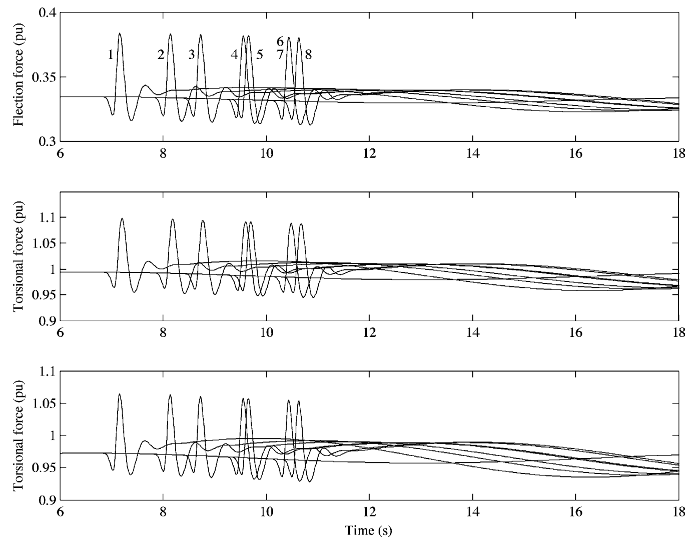

Fig. 5. Torsional shaft efforts with no controller.

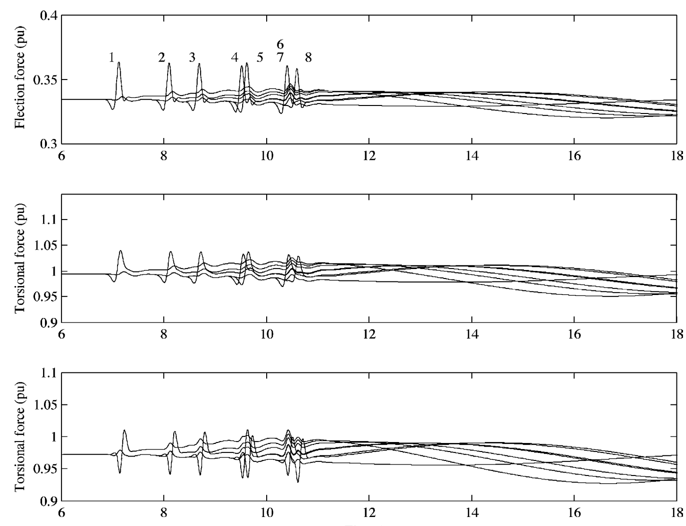

Fig. 6. Torsional shaft efforts with proposed controller.

IV. Simulation Results

A set of WECS of a real wind farm, geographically located as shown in Fig. 4, is considered in the simulations shown later, where a gust is propagated as indicated in the same figure.

When the proposed controller is missing, $p_s = 0$, the mechanical efforts in the first row of generators (#1 to #8) are shown in Fig. 5, where the top plot represents the flection efforts in the blades and the middle and bottom plots are the torsional effort in the hub-gear box and gear box machine's rotor shafts, respectively. Similar results are obtained for the remaining generators.

When the proposed control is applied, the efforts obtained in the presence of the same gust are shown in Fig. 6. Although a complex six-mass model, and measurement, control, and actuation delays are considered, an important reduction in mechanical efforts, such as flection moments in blades and torsional efforts in shafts, is obtained.

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