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Research paper

Power split transmissions for wind energy systems

Giacomo Mantriota

Dipartimento di Meccanica, Matematica e Management, Politecnico di Bari, Viale Japigia, 182, Bari – Italy

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ABSTRACT

To optimize the power produced in a wind turbine, the turbine speed should vary with the wind speed. Currently, in order to match the grid requirements, variable speed wind turbines incorporate expensive power electronics to convert the variable frequency power to a constant frequency. This paper deals with the performance of power split transmissions in wind energy systems. Through such systems, it is possible to bring significant benefits to the turbine and the generator. Indeed, the turbine could operate at maximum efficiency levels and the generator could produce electric power at a desired frequency. The aim of this paper is to identify the power split configurations that require the minimum rated power of the regulator system (mechanical CVT or servo-motor/generator), to reduce costs and the power losses.

1. Introduction

The conversion of the wind energy into electric energy is particularly problematic due to the variations of the wind speed. Wind turbine rotors achieve their maximum efficiency at a particular tip-speed ratio [1]. Wind turbines with constant speed, in which the rotor is connected to a generator at a fixed speed ratio, operate at very low efficiency. To increase the efficiency of the wind turbines, variable speed systems are normally applied in order to change the angular speed of the rotor according to the wind speed profile [1,2]. In these systems, the turbine runs at a tip speed ratio which ensures its maximum efficiency.

Variable speed systems present other advantages in that the turbine can operate as a flywheel, smoothing the torque variations caused by varying wind conditions, it is less sensitive to the wind pattern of a given location and emits less noise [1,3].

Currently, an overgear is used to connect a wind turbine to an electric generator. For smaller machines, the whole output must be transformed using power electronics to allow the speed of the generator to be decoupled from the grid frequency [2,4]. The generator is decoupled from the grid by a converter that works at the same rated power. In such configuration, the generator rotates with variable speed thus operating, in many cases, in conditions characterized by low efficiency. On larger machines, this becomes very expensive so the solution of the doubly fed induction generator was established [2,4]. In this case, the speed of the rotor does not have to be synchronous with the grid, then it can be connected directly. This is achieved by controlling the frequency of the rotor magnetic field so that it is no longer DC in the rotating frame of the rotor.

The development of novel, more reliable and efficient wind turbine systems is of fundamental importance in order to optimize the wind energy recovering [5–7].

E-mail address: giacomo.mantriota@poliba.it

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Nomenclature

C_P	power coefficient
CVT	Continuously variable Transmission
IS	Input split
k_1,k_2,k_3	Constants
rr	Ratio range of the CVT
rr_W	Ratio of rated and start wind speed
T_i	Torque of the ith path
OS	Output split
P_{CVT}	CVT power
$P_{CVTM}\|_{OS}^{I}$	Maximum CVT power in Output Split and type I power flow
$P_{CVTM}\|_{OS}^{III}$	Maximum CVT power in Output Split and type III power flow
$P_{RegM}\|_{IS}^{III}$	Maximum Regulator power in Input Split and type III power flow
$P_{RegM}\|_{IS}^{I}$	Maximum Regulator power in Input Split and type I power flow
PG	Planetary Gear train
P_T	Turbine power
P_{T_R}	Rated turbine power
P_{Reg}	Regulator power
PS-CVT	Power Split CVT
R	Maximum radius of wind rotor
S	Wind turbine frontal area
Subscript M	Maximum
Subscript m	Minimum
Subscript Opt	Optimal
u	Peripheral speed of the turbine
V_W	Wind speed
V_{WS}	Wind speed at which the turbine starts
V_{WR}	Rated wind speed
τ_W	Speed ratio of the Planetary Gear train
τ_{CVT}	Speed ratio of the CVT
τ_{ij}	Transmission ratio of the ith and jth path
ω_i	Angular velocity of the ith path
ω_T	Turbine angular velocity
ρ	Air density
λ	Ratio between the peripheral speed of the turbine and the wind speed

The feasibility of incorporating a Continuously Variable Transmission (CVT) between a wind turbine and an electric generator (GEN) has been examined in Ref [8–9]. There are also mechanical variators based on digital hydraulics (Artemis) that are being applied to wind power [10]. This solution brings benefits in terms of energy recovering since the transmission can vary automatically the speed ratio according to any variation of the wind speed and reduces the costs associated with the expensive power electronics since the generator is able to produce electric current at constant frequency. However, the CVT has low efficiency compared to the one of a fixed gear transmission system [9].

Power split transmissions are often employed to improve the performance of a continuously variable transmission [11, 12]. Their basic scheme includes a Planetary Gear train (PG) and a CVT, be it mechanical, electrical or hydraulic. Power Split Continuously Variable Transmissions (PS-CVT) have been investigated in many studies, which focused on the efficiency [12–14], experimentally verified through a test bench [13, 15], the functional design and the original types of PS-CVT [16]. There are two possible configurations of PS-CVT [12]: input split (IS), obtained if the PG is placed at the input shaft and Output split (OS), obtained if the PG is placed at the output shaft.

Recently some papers have suggested to connect a wind turbine rotor to a generator through a power-split hydrostatic transmission [17, 18] to maximize the turbine efficiency. In other previous papers [19–23], hybrid CVT transmissions have been proposed for variable speed wind turbines, in which the transmissions consist of a single PG controlled by a servo-motor.

This paper compares the performance of the IS and OS power systems, for variable speed wind turbines. For each configurations, the possible power flows and, in particular, the power of the control system with respect to the input power is presented. The aim of this work is to identify configurations that require the minimum rated power of the control system (mechanical CVT or servo-motor/generator), to reduce costs and power losses.