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DEVELOPING A CONTROLLER FOR WIND POWER PLANTS

A controller is proprsed to track the wind power plants (WPP) in the whole wind speed range. The control procedure is aimed at tracking the wind turbine's maximal power coefficient by adjusting the generator's rotational speed.

Keywords: PID controller, wind power plant, power coefficient, tip-speed ratio.

1. Introduction. WEP are the alternative energy sources, and the works towards the creation of alternative sources of energy with the constant increase in the cost of fossil fuels are actual.

The aim of this article is the development of a controller to track the WPP in the whole wind speed range.

2. The proposed power circuit modeling

As shown in Fig. 1, the proposed WPP consists of a small tri-blade horizontal axis wind turbine (HAWT), a mechanical transmission gearbox, a three-phase permanent magnet synchronous generator (PMSG), a three-phase diode bridge, a DC/DC converter and a battery storage system.

The HAWT has a high aerodynamic power coefficient of wind turbines (WT) and its optimal rotor speed is relatively higher than that of the other types. These characteristics makes it most efficient and best suited for electric generation applications. The gearbox allows to meet the turbine rotor speed with the generator rotor speed. The PMSG is the best suited generator for low power wind energy applications due to its simplicity and low costs. In particular, the PMSG of the proposed scheme can be obtained off-the-shelf; it will not need to be specially designed for this kind of application.

Similar schemes have been previously proposed, studied and verified. The main differences from the proposed structure will be the PMSG and the DC/DC converter. A boost converter is used to enhance the power production in the light wind range [1] and a buck-boost converter is used to control the rotor speed [2].

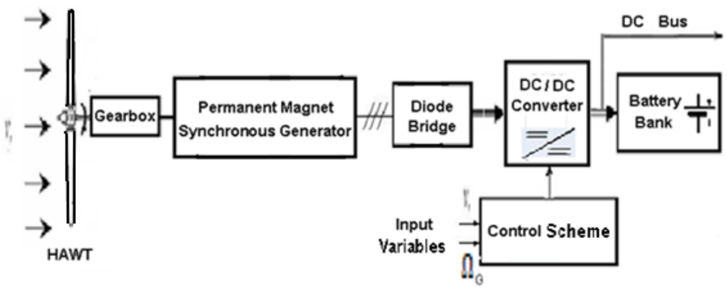

Fig. 1. The proposed wind energy system

The proposed variable speed scheme combines the principal advantages of previous approaches: a non chopped waveform in the input current and the possibility of step-down and step-up voltage conversion.

The proposed cascaded converter has an input series inductor L_1 ; with this element, the input current will have a main DC component and a ripple that depends on the converter design.

The converter step-up capacity raises the operation range for light winds by reducing the system minimal wind and allows to track the maximum power point [1-2]. The converter step-down capacity allows a voltage reduction in the generator when wind is higher than rated [2].

3. The proposed control scheme modeling

The system control procedure is based on two decoupled stages: the first stage generates the DC voltage reference to obtain the desired rotor speed in a closed loop control procedure. The second stage is the converter control that reaches the desired voltage value using a simple open loop scheme.

It is known that the mechanic power of the WT depends on air density, blade sweeping area, the wind speed and the power coefficient. The air density and the sweeping area can be considered as constant parameters and the wind speed is not controllable. Power coefficient is characteristic of the WT and its value depends on tip speed ratio. It is known that there is an optimal λ that maximizes the power coefficient (C_p), therefore; for each wind speed value, there is an optimal rotor speed that maximizes the WEP output power. The well-known formula of wind energy for WT is given by:

$$P = \frac{1}{2}\rho A C_p v^3, \tag{1}$$

where ρ is the air density, A - the blade sweeping area, and v - the wind speed. The mechanical characteristics of WT are defined by the WT aerodynamics and can be obtained from the aerodynamic characteristics of WT representing the dependence of C_p versus the tip-speed ratio $\lambda = \Omega R/V$, where Ω is the WT rotor speed and R - the WT blade length. Since the curve C_p as a function of λ is non-linear and has a unique maximum at the point λ^*, from Eq.(1), in terms of the definition of λ, it follows:

$$P_i(\Omega) = P_t^* = \frac{1}{2}\rho A C_p^* \left(\frac{R}{\lambda^*}\right)^3 \Omega^3. \tag{2}$$

As the PMSG has no field control, the goal of the control system is to regulate the machine voltage to adjust the WEP rotor speed. The voltage control of the generator is carried out by the DC/DC converter, which modifies its input voltage by means of the duty cycle.

In general, control schemes need a rotor speed measurement for closed loop control purposes and the rotor speed is given by:

$$\Omega^* = \frac{\lambda^*}{R} v \,. \tag{3}$$

Once the output power measurement is known, the rotor speed reference can be written as:

$$\Omega^* = \frac{\lambda^*}{R}\left(\frac{2P}{\rho \cdot AC_p^*}\right)^{1/3} . \tag{4}$$

For simplicity reasons, equation (3) is used to validate the proposed power scheme. For this, the WT blade radius *R*, and the optimal tip speed ratio λ^* must be known.

The system rotor speed is controlled by a PID controller and the output control signal is the voltage reference to the cascaded converter control. Figure 2 shows the proposed speed control system scheme.

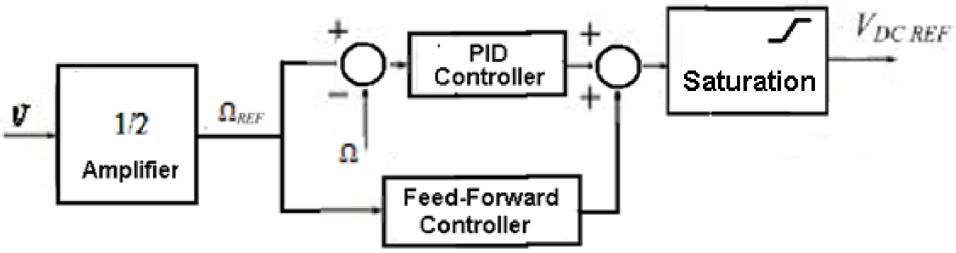

Fig. 2. The block diagram of the proposed speed control system

The proposed cascaded power converter is composed of an input boost converter plus an output buck converter. Each power converter is controlled in an independent and complementary way. To control the DC voltage, a feed-forward procedure is used.

To control the DC voltage, relations between DC voltages (diode bridge DC voltage V_{DC} and output battery voltage V_{Batt}) are considered.

The voltage gain A_v of buck and boost converters for continuous current mode are defined as:

$$A_{V,Buck} = \frac{V_0}{V_i} = D \,, \tag{5}$$

$$A_{V,Boost} = \frac{V_o}{V_i} = \frac{1}{1-D} \,. \tag{6}$$

So, as the battery voltage, which is the WPP output voltage, remains nearly constant and when the boost converter is in a stand-by mode (switch open, diode in forward mode), the control variable, when the buck converter is regulated, is D_{Buck}. The voltage reference value V_{DCREF} is obtained from the generator speed control and D_{Buck} is then:

$$D_{Buck} = \frac{V_{Batt}}{V_{DCREF}}. \tag{7}$$

When the boost converter is controlling the DC voltage for maximal power output, the buck converter is now in a stand-by mode (switch closed, diode in blocking state), the steady state value of the control variable for the step-up converter is D_{Boost} and the latter is obtained as:

$$D_{Boost} = 1 - \frac{V_{DCREF}}{V_{Batt}}. \tag{8}$$

Figure 3 shows the proposed open loop control scheme for the cascaded DC converter, based on a pulse width modulation (PWM) scheme, where the duty cycle for each converter is calculated and converted into gate signals. The DC voltage reference is compared to the battery voltage to define which converter will operate and a simple digital circuit completes the task.

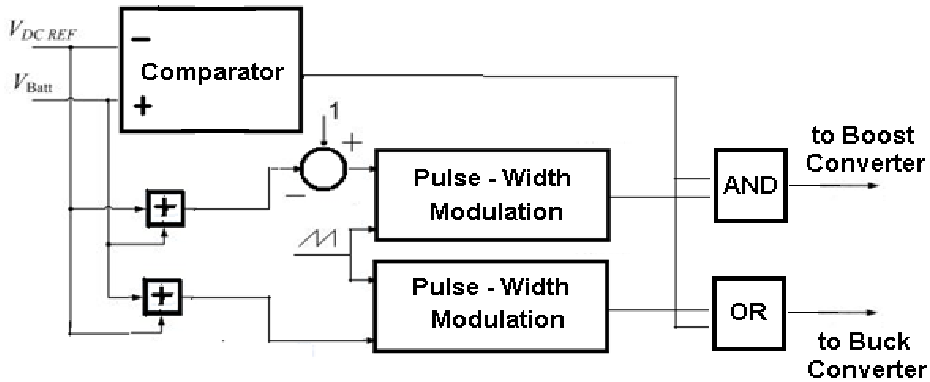

Fig. 3. The block diagram of the proposed open loop control for the cascaded converter

4.Conclusion. The WPP is validated by computer simulation, using Matlab PowerSym toolbox[3]. The WT model is obtained from Eq (1) and from an approximation of the C_p curve in terms of the tip speed ratio (λ). Therefore, input signals for the WT model are the wind speed and system rotor speed. The gearbox was modeled as a gain for simplicity reasons.

The PMSG was chosen from the PowerSym preset generators list. With the goal of a correct observation and analysis of the proposed power and control system behavior, the wind was supposed as a known and controllable parameter. The proposed WPP was verified by simulation for a standalone application. Results of the rotor speed control are shown in Figure 4. Figure 4 shows the rotor speed behavior for successive raising steps of wind speed (3 m/s to 4 m/s then 5 m/s).

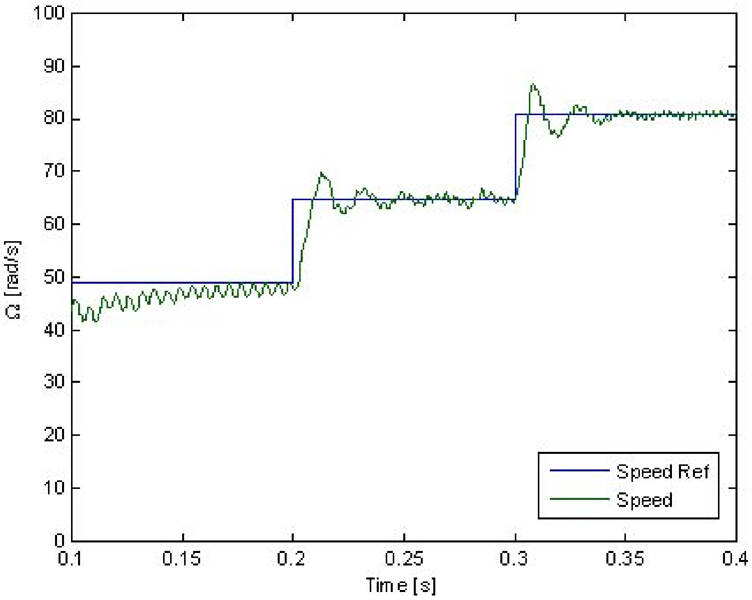

Fig. 4. Simulation results for step changes in wind speed from 3 to 4m/s and 4 to 5m/s

From Figure 4, it can be observed that the proposed control system can follow correctly the speed reference. A less than 20% overstep is observed when the wind speed step rises; nevertheless, when the wind speed step goes down, the obtained overstep is much higher, nearly 50 %. Some small oscillations are observed in steady state also. These effects can be corrected by adjusting the PID controller parameters and can be explained by nonlinear and high frequency dynamics that are neglected by the control system.

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Լ.ՅՈՒ. ԹՈՐՈՍՅԱՆ

ԿՈՆՏՐՈԼԵՐԻ ՄՇԱԿՈՒՄԸ ՀՈՂՄԱՅԻՆ ԷԼԵԿՏՐԱԿԱՆ ՏԵՂԱԿԱՅԱՆՔՆԵՐԻ ՀԱՄԱՐ

Քամու ամբողջ արագության միջակայքում հողմաէլեկտական տեղակայանքների (ՀԷՏ) ղեկավարման համար առաջարկվել է կոնտրոլեր: Ղեկավարման ընթացակարգի նպատակն է հետևել քամու էներգիայի օգտագործման գործակցի առավելագույնին՝ գեներատորի պտտման արագության փոփոխության միջոցով:

Առանցքային բառեր. ՀԻԴ կոնտրոլեր, հողմաէլեկտրական տեղակայանք, հզորության գործակից, արագընթացություն:

Г.Г. КИРАКОСЯН, В.Г. ХАЧАТУРЯН, В.Д. БАРСЕГЯН, Л.Ю. ТОРОСЯН

РАЗРАБОТКА КОНТРОЛЛЕРА ДЛЯ ВЕТРОВЫХ ЭНЕРГЕТИЧЕСКИХ УСТАНОВОК

Предложен контроллер для управления ветровыми энергетическими установками во всем диапазоне скорости ветра. Целью процедуры управления является следование за максимумом коэффициента использования энергии ветра путем изменения скорости вращения генератора.

Ключевые слова: ПИД контроллер, ветровая энергетическая установка, коэффициент мощности, быстроходность

ՀՏԴ 62-50

Մ.Գ. ՈՒՍԵՊՅԱՆ

ԿՐԹԱԿԱՆ ԱՌԱՐԿԱՆԵՐԻ ԱՇԽԱՏԱՏԱՐՈՒԹՅԱՆ ՀԱՇՎԱՐԿԸ ՏՐՎԱԾ ՍԱՀՄԱՆԱՓԱԿՈՒՄՆԵՐԻ ՀԻՄԱՆ ՎՐԱ

Ներկայացվել է առարկաների աշխատատարության հաշվարկի մեթոդ՝ հիմնված ուսումնական պլանում միջառարկայական կապերի և տրված սահմանափակումների վրա: Առաջարկված մեթոդը թույլ է տալիս ավտոմատացնել ուսումնական պլանի նախագծման գործընթացը՝ հաշվի առնելով այդ թվում շահակիցների հարցումների արդյունքում ձևավորված առարկայական կշիռները և ուսումնական պլանի վրա դրված գործող սահմանափակումները:

Առանցքային բառեր. ուսումնական պլան, առարկաների աշխատատարություն, առարկայական կշիռ, շահակից:

Արդի պայմաններում կրթության և գիտության ոլորտի ընթացակարգը պահանջում է կրթության համակարգի արձագանք ընթացող արագ փոփոխություններին: