A New combined MPPT-Pitch Angle control of a Large Variable Speed Wind Turbine in Different Operating Areas based on Synergetic control

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Article Info

Article history:

Received March 05,2022
Revised April 30, 2022
Accepted June 08, 2022

Keywords:

Maximum power point tracking (MPPT) control
Pitch control
Wind energy conversion system (WECS)
Synergetic Controller (SC)
Macro variable function

ABSTRACT

The aim of this paper is to create a novel combination between two controls, maximum power point tracking (MPPT) and Pitch angle control system of a variable-speed wind turbine. The main objective sought is to achieve the maximization of the power produced by the fixed pitch angle turbine through the MPPT control in the zone 02 of operation. Then, limit the power to its nominal value by using the Pitch control with variable pitch angle in zone 03 of operation. Our contribution will be to propose strategies based on two types of controllers. The first is the control by the MPPT control, it is applied in light winds to extract the maximum power. The second is Variable Pitch Control, which is applied in strong winds to keep power constant at its nominal value, as well as protecting the wind turbine from high winds. For this, linear and non-linear control laws (PI, SC) respectively are implemented to achieve the defined objective. The simulation results show the feasibility and effectiveness of the techniques used.

I. Introduction

World energy consumption has experienced a huge increase in recent years, due to massive industrialization which tends to increase more and more, and more precisely in certain geographical areas, particularly in the countries of Asia. Because environmental problems, greenhouse gas emissions, pollutions, and the instability of the prices of these sources in world markets are factors that have prompted industrialized countries to resort to renewable energy to meet their energy needs while at the same time maintaining a margin of economic and environmental safety [1], [2]. The challenges of future energy require the development of renewable energy as alternative sources, clean and inexhaustible [3], [4]. Wind power is the fastest generating technology among renewable energy sources. Its use does not cause any release (no greenhouse effect) and does not produce toxic waste [5]. Over the last years, with technological advancement, wind power has grown rapidly and becomes the most competitive form of renewable energy. Thanks to MPPT algorithms and controllers, Variable Speed (VS-WECS) is capable of generating electrical power under all wind speed ranges by controlling shaft speed based on wind speed. Furthermore, they are more preferred than Constant Speed WECSs (CS-WECS) because of the fact that they can capture more energy under the same wind conditions [6]. According to Betz's law, only 59.3% of total available wind energy can be converted into mechanical energy considering no mechanical losses in the system [7]. Therefore, to extract the maximum power under variations of wind speed, maximum power point tracking (MPPT) strategies play an important role in wind power conversion systems (WECS) because they maximize the power extracted from the wind, and therefore optimize the conversion efficiency.

Many types of controllers are implemented for Maximum power point tracking (MPPT) in wind power conversion systems (WECS) [8], [9]. This article proposes a new approach based on Synergetic Control (SC) theory. This theory was introduced by Russian scientists in general terms. The synergistic control has a similar function to sliding mode control (SMC) but the chattering phenomenon is eliminated. The basic idea is to force the system to the desired manifold using continuous controls law.

Our contribution will be to propose strategies based on two types of controllers. The first is the control by the MPPT control, it is applied during light winds to extract the maximum power. The second is the Variable Pitch control, it is applied during strong winds to keep the power constant at its nominal value, as well as the protection of the wind turbine against violent winds. These control laws are the objective of the variable speed wind turbine.

II. Different functioning zones of the wind turbine

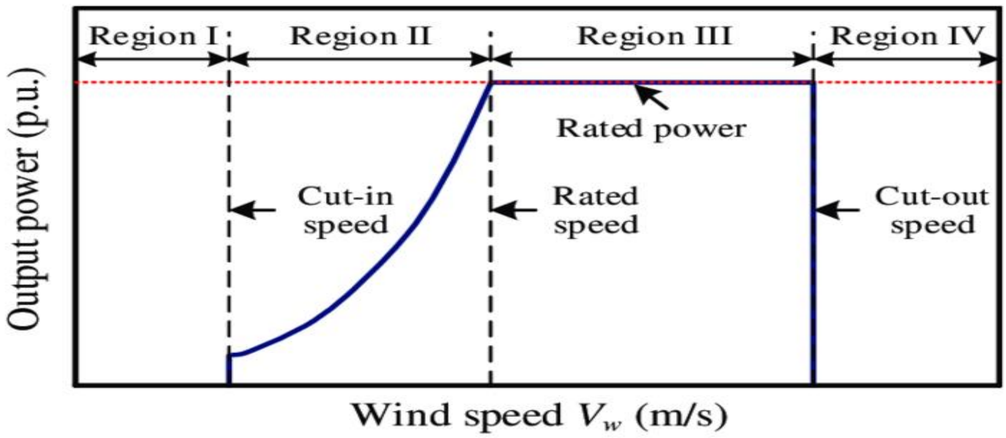


Figure 1. Different functioning zones of the wind turbine.

Zone 1: Corresponds to very low wind speeds, which are insufficient to drive the wind turbine and produce power (P=0).
Zone 2: In this zone (MPPT), the pitch angle β is kept constant, and this is the control of the electromagnetic torque of the generator that will be implemented in order to capture the maximum power for each wind speed.
Zone 3: Here the speed of the generator is kept constant at its maximum as opposed to an appropriate engine torque. The increase in wind speed will therefore be accompanied by a decrease in the coefficient Cp and a slower increase in the recovered power. When the maximum power of the generator is reached, the angle of orientation of the blades is modified in order to further degrade the coefficient Cp.

Zone 4: When the wind speed becomes too high, a device emergency stops the wind turbine and secures it to prevent any damage.

III. Modelling of the wind turbine

III.1. Wind Turbine Modeling

The wind profile can be modelled by:

$$V(t) = 10 + 0.2\sin(0.1047t) + 2\sin(0.2665t) + \sin(1.2930t) + 0.2\sin(3.6645t) \quad (1)$$

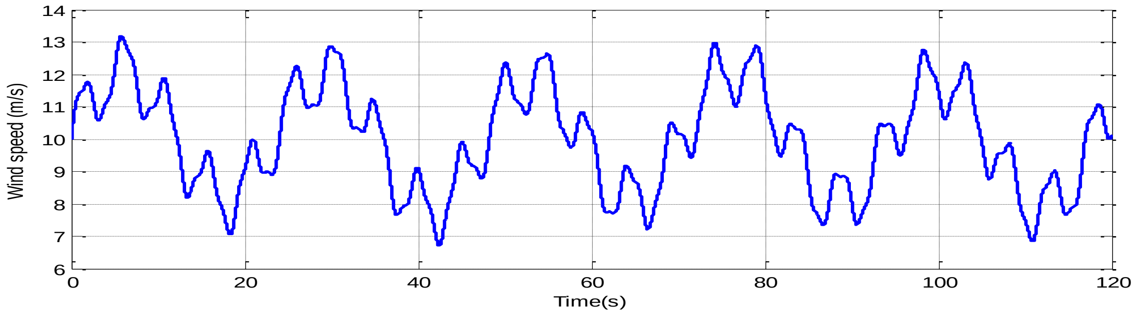


Figure 2. Wind speed profile.

The nonlinear expression for aerodynamic power captured by the wind turbine is given by [10]:

$$P_{aer} = \frac{1}{2} C_p(\lambda, \beta).\rho.\pi.R^2.V^3 \quad (2)$$

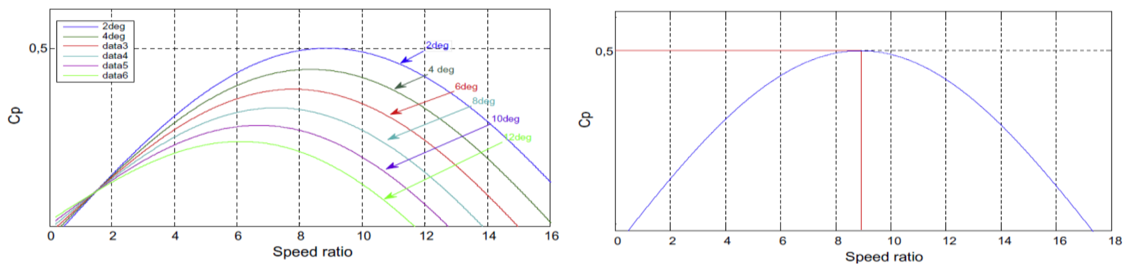
The tip-speed ratio (TSR) λ is calculated by:

$$\lambda = \frac{R.\Omega_{tur}}{V} \quad (3)$$

Where P_{aer} the extracted power from the wind, ρ is the air density [kg/m^3], R radius of the turbine blade (m), V is the wind speed [m/s], $C_p(\lambda,\beta)$ is the power coefficient wich is a function of both tip speed ratio (TSR) λ and blade pitch angle β (deg). Several numerical approximations exist for $C_p(\lambda,\beta)$. Here the used relation is given by:

$$C_p(\lambda,\beta) = (0.5 - 0.167(\beta - 2))\sin\left[\frac{\pi(\lambda + 0.1)}{18.5 - 0.3(\beta - 2)}\right] - 0.00184(\lambda - 3)(\beta - 2) \quad (4)$$

The Eq (4) simulation is shown in Fig.3.



(a) (b)

Figure 3. Power Coefficient versus tip-speed ratio for various values of β.

For a constant β, there is only one fixed value of TSR $(\lambda_{opt} = 9.14)$ for which C_p is maximum $(C_p^{max} = 0.5)$. This special value λ_{opt} is known as the optimal peak speed ratio, it can be expressed by:

$$\lambda_{opt} = \frac{\Omega_{ref}.R}{V} \quad (5)$$

Where Ω_{ref} is the rotor speed reference (rad/s).

III.2. Gearbox Model

The function of the gearbox is to convert the mechanical speed of the turbine into the power generation speed, and the pneumatic torque into the gearbox torque according to the following mathematical formula:

$$\begin{cases} T_g = \dfrac{T_{aer}}{G} \\ \Omega_{tur} = \dfrac{\Omega}{G} \\ T_{aer} = \dfrac{P_{aer}}{\Omega_{tur}} \end{cases} \quad (6)$$

The basic dynamics equations allow to determine the evolution of the mechanical speed based on the total mechanical torque applied to the rotor, which is the sum of all the torques applied to the rotor:

$$J\frac{d\Omega}{dt} = T_g - T_{em} - f.\Omega \quad (7)$$

Where: Ω : Mechanical generator speed; T_g : Torque applied on the shaft of the generator; T_{em} : Electromagnetic torque; J: the total moment of inertia, f : The viscous friction coefficient, T_{aer} : is the aerodynamic torque; G : is the gear box ratio.

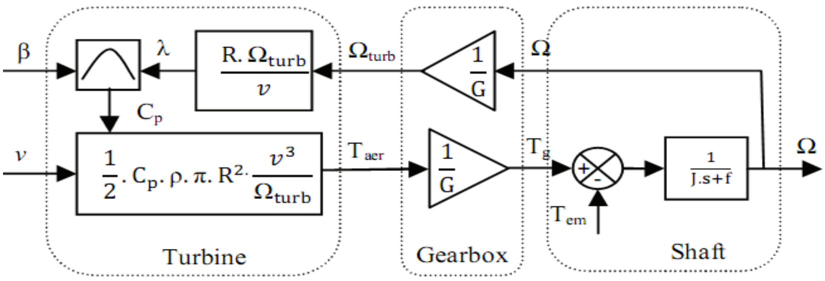


Figure 4. Wind turbine model.

IV. Control Strategies

IV.1. MPPT Control Pricipe

The objective of MPPT is to optimize the captured wind energy following the optimal speed. To recover as much energy as possible from the wind turbine, we must constantly adapt the mechanical speed of the PMSG to the speed of the wind. The electromagnetic torque drawn from the MPPT control is then applied to the PMSG to ensure that the generator runs at its optimum speed. The figure is shown in Figure 5, illustrating the wind turbine model with MPPT control model:

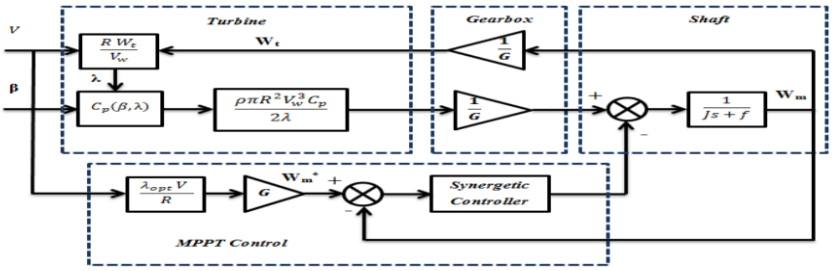


Figure. 5. MPPT-synergetic method bloc diagram.

IV.2. SYNERGETIC CONTROLLER DESIGN

According to Synergetic Approach (SA), we will select the first set of macro-variables as equation (8):

$$\psi = \Omega_{ref} - \Omega \quad (8)$$

This derivative is:

$$\dot{\psi} = \dot{\Omega}_{ref} - \dot{\Omega} \quad (9)$$

The expected dynamic evolution of the macro-variable is given as a function of: [11]

$$T\dot{\psi} + \psi = 0 \qquad T \succ 0 \quad (10)$$

Whereas the derivative of the total macro-variable is noted by $\dot{\psi}$, and T is a parameter design which designates the convergence rate from the closed loop system to the manifold that is to be specified by $\psi = 0$.

Combining these equations (8), (9), and (10), we get the electromagnetic motor torque directly without the PI regulator as the following control law:

$$T_{em-ref} = T_{em} = \frac{J}{T}\left[\frac{Tf}{J}\Omega - \frac{TT_g}{J} + (\Omega_{ref} - \Omega)\right] \quad (11)$$

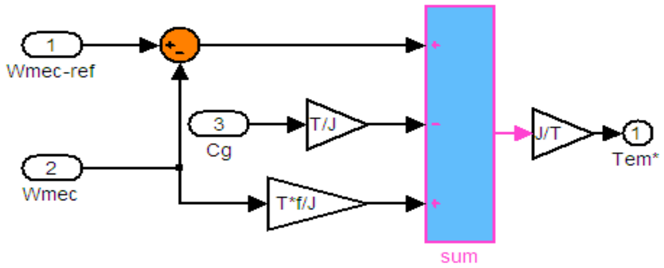


Figure 6. Configuration of the speed control with Synergetic Control.

IV.3. Pitch angle control

The pitch angle control of blades is a good and useful method to protect the electric devices from extra high power and ensure the continuity of energy production by reducing the power into the nominal one, (region.III). When the wind speed is higher than the rated one, the power is higher than its nominal value, so the value of the pitch angle β must increase to reduce the power coefficient Cp value in a way to limit the power at the constant nominal value of the power, [12], [13].

The modeling of the Pitch system is done in three steps [14]:

a. Generation of the reference angle β*.

b. Orientation angle regulation.

s. Regulation of the dimming speed of the angle.

Figure 7 illustrates the principle of blade pitch angle variation.

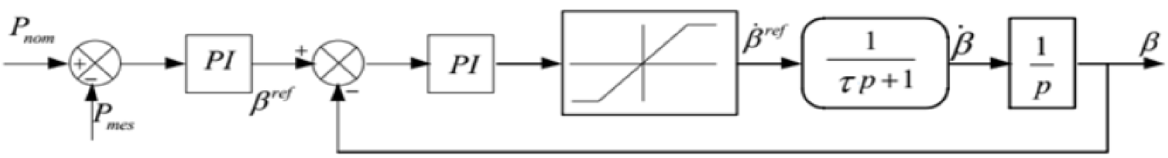


Figure 7. PI regulation of the orientation angle of the blades.

The dynamics of the Pitch actuator is generally described by a first order transfer function such as [15], [16]:

$$\beta = \frac{1}{1+\tau.s}\beta_{ref} \qquad (12)$$

β_{ref} : Reference pitch angle.

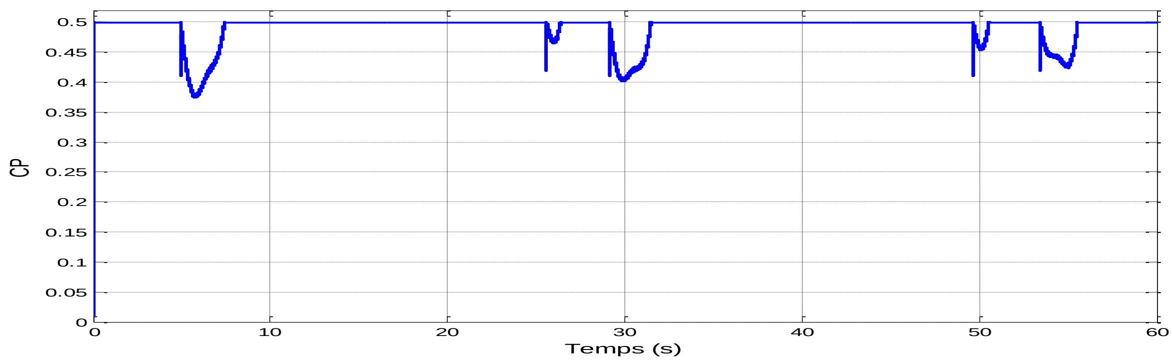
τ : Pitch actuator time constant.

V. SIMULATION RESULTS

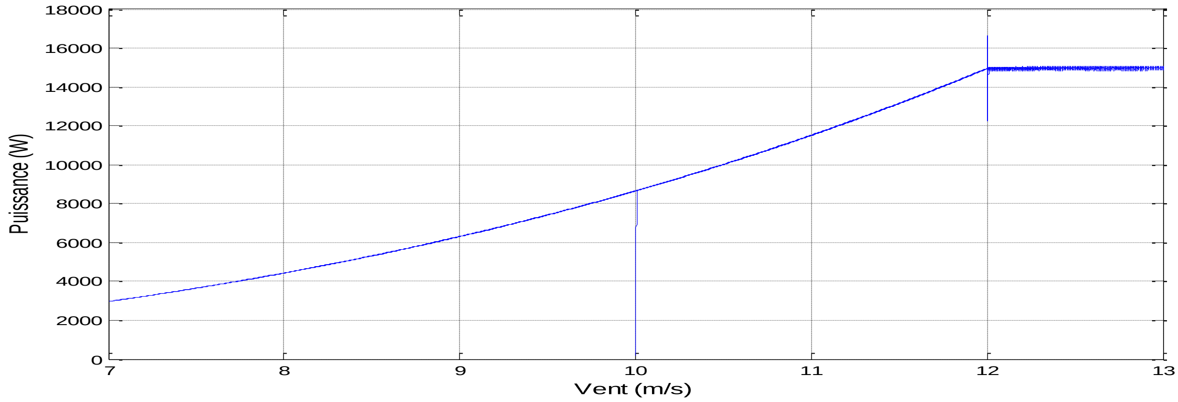
To evaluate the performance and effectiveness of the proposed method (MPPT control, pitch angle control), it is implemented in the MATLAB / SIMULINK software environment. The selected system parameters for wind turbines given in Table (1).

Table 1. Parameters of WT and PMSC

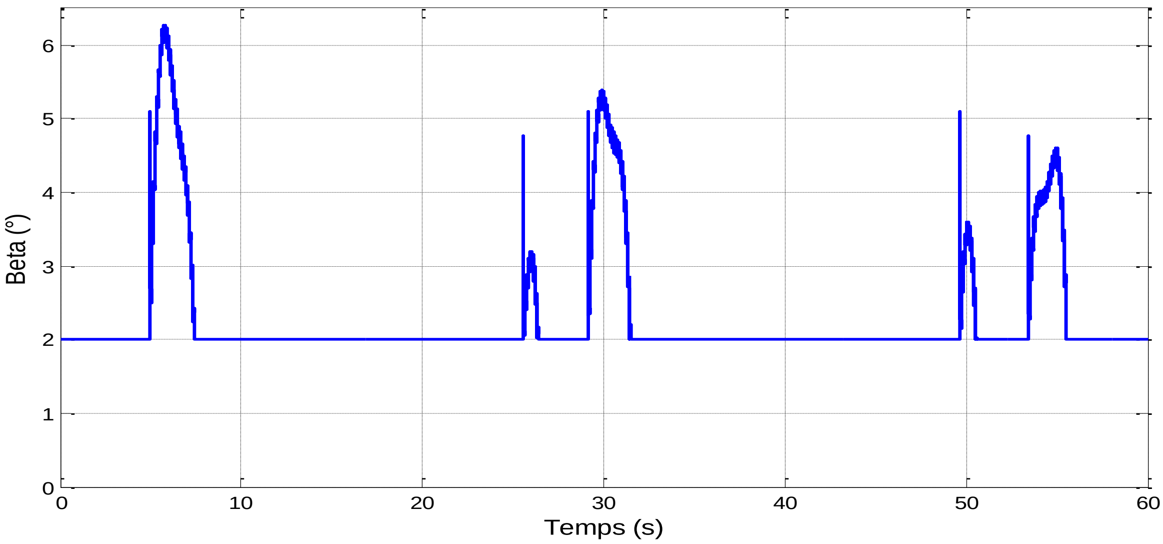
WT parameters	
Parameters	**Values**
Density of air	1.22 kg/m^3
Radius of rotor	3 m
Gear box ratio	G =1
total inertia	16 kg.m^2
Total viscous friction coefficient	0.06 N.m/s



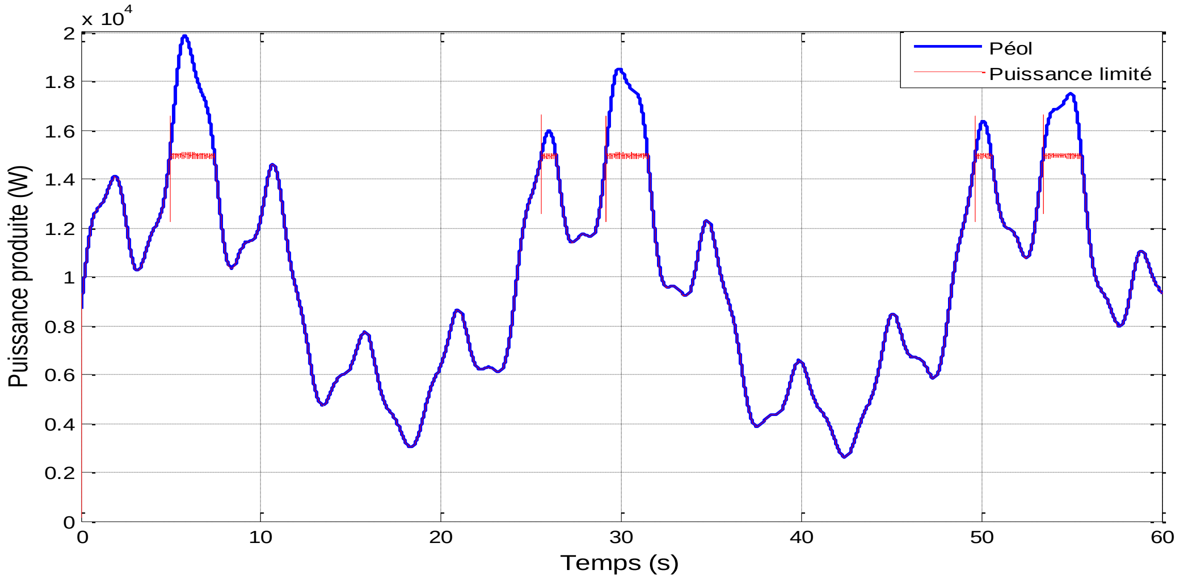
(a) Power coefficient CP.



(b) Wind turbine power as a function of wind speed.



(c) Shape of the Beta pitch angle.



(d) Power without and with limitation.

Figure 8. Results of the operatin zones with MPPT and Pitch controller.

Figure (8) illustrates the variation of different quantities for different wind speeds. Figures (8.a) and (8.c), represent the power coefficient and the pitch angle (β), respectively. It can be seen that for wind speeds below the nominal speed (≈12 ms), the MPPT technique ensures the optimization of the power captured by the turbine. This is ensured by keeping the Cp at its maximum value.

When the wind speed exceeds the rated speed, the power is limited to its rated value. This power limitation is obtained thanks to a degradation of the power coefficient Cp by increasing the pitch angle (β), figures (8.c) and (8.d).

Figure (8.b) represents the mechanical power of the turbine as a function of the wind speed, it can be observed that the power keeps a limit value for high wind speeds despite the turbine being able to produce more power. This is thanks to the blade orientation system (pitch control).

These results confirm the validity of the controls applied in all the operating zones of the wind turbine.

III. Conclusion

In this work, the operating areas of a variable speed wind turbine, in order to extract the maximum power have been described. The first MPPT command imposes operation in zone two, while the second variable pitch command is applied to have a limitation of the power generated by the turbine in the presence of strong winds zone three. The purpose of each of the orders as well as their procedures for design have been described. The simulation results show the interest of the mechanical speed control in the two operating zones. It is clear that the pitch angle varies proportionally with the speed of rotation of the generator when the latter reaches its nominal value.

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