

APPLICATION OF FUZZY LOGIC TO CONTROL THE POWER OF COAXIAL GENERATORS USING DUAL POWER HETEROGENEOUS POWER MACHINES

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ABSTRACT

Ship power stations are becoming more and more modern with today's energy management and monitoring control systems. With large tonnage ships, the power station always aims at an optimal exploitability in the sea voyage to reduce energy consumption, reduce operating time and reduce noise, reduce environmental pollution, avoid adverse impacts on humans as well as the natural environment. For large vessels, the transmitting station is usually designed with coaxial generators working together with diesel-generator (DG) assemblies. The model of a generating station using the main machine to drive the generator in combination with several diesel generator sets for the purpose of generating electricity is a model that is appreciated for both technical and economic features. With dimming controllers, there is a new development direction in the field of system control research. Dimming controllers are, in principle, nonlinear static controllers. They can be designed with a given system quality to an arbitrary precision and work according to the principles of human thinking. On the basis of the mathematical model of DFIG is built on an appropriate static coordinate axis, oriented according to the grid voltage vector to have an isolation between the effective power control and the reactive power on the stator side of the generator. With this reference coordinate system orientation technique, it is possible to control the consumption or transmission of reactive power completely independently of the control of the real power operating modes. Because the DFIG stator is directly connected to the grid and the stator voltage is fixed according to the grid voltage, so the target of independent control of the effective power and the reactive power on the side of the DFIG stator of the generator is attributed to the goal of independent control of the two α shaft components and the β of the stator current vector in the normal operating mode.

1. INTRODUCTION

Today, the growing level of electrification and automation on ships goes hand in hand with the increase in the capacity of the power station. In the mining process, when using a coaxial generator, the cost of 1KWh is about 50% lower than when the generator solution has its own drive motor, this is reflected in a number of reasons as follows:

The first is that it enhances the efficiency of using the main machine compared to the efficiency of using the auxiliary machine through reducing fuel consumption.

The second is that the main machine often uses heavy oil, which is much cheaper than the oil used for the auxiliary machine.

The third is to reduce the consumption of lubricating fuel for the main machine.

Fourthly, during the journey time on the sea, the auxiliary machine is not work, so it significantly reduces the operating and exploitation time, reducing the cost of repair and maintenance. To evaluate the benefits of applying coaxial generators, first of all, we find that the working time of the main machine, ie the journey time at sea compared to the berth time is quite short, even container ships have a very high turnaround capacity, the ratio of journey time to berth time is always lower. When the main machine is involved in generator duty on a long journey, the operating time of other diesel-generator generators in the station will be less and thus it will last. For the coaxial generator system configuration equipped with asynchronous generators powered from two sides, there are outstanding advantages that DFIG's stator is connected directly to the grid, while the rotor is connected to the grid via controllable power electronics. Because the control device for DFIG is located in the rotor, the power of the

control device is only approximately 1/3 of the generator power, and the resulting energy flow flows directly from the stator to the grid. This is the outstanding advantage of DFIG compared to other generator devices with a controller located between the stator and the grid. However, that structure makes DFIG a lot harder to control, especially in the event of an incident on the grid. When a problem occurs on the power grid, the busbar voltage will be suddenly reduced, causing the magnetic flux in the generator to vibrate very strongly. This magnetic flux will cause the induced electromotive force applied to the rotor and if the value of these electromotive forces is large, the trigger can cause a very large current, damaging the converter. Satisfying the above problem requires the ability to independently control between the acting power and the reactive power to help the source emitted by DFIG be of high quality. The DFIG system gives us the ability to independently control the applied power and reactive power of the stator terminal through a power converter located at the rotor. Due to its nonlinear nature, DFIG control is more complex than conventional motor control. Therefore, for conventional DFIG control, the system is oriented like a mains voltage vector field or stator magnetic flux for nonlinear analysis as used in nonlinear system control schemes.

The use of fuzzy logic is seen as a simple control option for nonlinear systems even those with uncertain models that are susceptible to interference.

2. METHODOLOGY

Mathematical model of coaxial generators on ships in static coordinate axis $\alpha\beta$

Assumptions when considering a three-phase asynchronous winding rotor

-The stator and rotor windings are arranged spatially symmetrically, stator and rotor windings are assumed to be connected in a Y-Y shape

-Uniform air gap

-Ignoring eddy current losses and ferromagnetic losses

-Failure to take into account the saturation of magnetic materials

-The phenomenon of ring hooking of the magnetic flux between the stator and rotor occurs only with elementary harmonics. The magnetization current and magnetic field are sinusoidally distributed on the surface of the magnetic slit

-The system of equations is obtained on the basis of the fundamental waves of current, pressure and magnetic flux quantities

Derived from the stator and rotor phase voltage equation of the wire rotor three-phase asynchronous electric machine:

$$v_{as} = R_s i_{as} + \frac{d\psi_{as}}{dt}, v_{bs} = R_s i_{bs} + \frac{d\psi_{bs}}{dt}, v_{cs} = R_s i_{cs} + \frac{d\psi_{cs}}{dt} \quad (1)$$

$$v_{ar} = R_r i_{ar} + \frac{d\psi_{ar}}{dt}, v_{br} = R_r i_{br} + \frac{d\psi_{br}}{dt}, v_{cr} = R_r i_{cr} + \frac{d\psi_{cr}}{dt} \quad (2)$$

Using the above formula, we have the stator voltage equation in space vector notation:

$$v_s = R_r \cdot i_s + \frac{d\psi_s}{dt} \quad (3)$$

Similarly, the rotor voltage equation in space vector notation is written in its own natural coordinate axis system:

$$v_r = R_r \cdot i_r + \frac{d\psi_r}{dt}$$

The rotor quantities represented in the $\alpha\beta$ -axis system are comparatively more complex because the rotor itself is rotating in the stator axis. The rotor quantities are attributed to the same coordinate axis system $\alpha\beta$ attached to the stator according to the ratio of loops k_T and conversion angle θ_r

$$\begin{aligned} v_r^s &= k_T e^{j\theta_r} v_r^r \\ i_r^s &= \frac{e^{j\theta_r}}{k_T} i_r^r \\ \psi_r^s &= k_T e^{j\theta_r} \psi_r^r \end{aligned} \quad (4)$$

$k_t = N_s / N_r$ is the stator and rotor ring ratio

$\theta_r(t)$ is the angle of position of the rotor in degrees of electricity [elec.rad]

$$\theta_r(t) = \int_0^t \omega_r(t) dt + \theta_r(0) \quad (5)$$

ω_r is the angular velocity of the rotor [elec.rad/s].

Note:
$$\frac{d\psi_r^r}{dt} = \frac{1}{k_r} \frac{d}{dt} (\psi_r^s e^{-j\theta_r}) = \frac{e^{j\theta_r}}{k_t} \left[\frac{d\psi_r^s}{dt} - j\omega_r \psi_r^s \right] \quad (6)$$

$$v_r^s = R_r i_r^s - j\omega_r \psi_r^s + \frac{d\psi_r^s}{dt} \quad (7)$$

The magnetic flux vector is represented in terms of current vectors:

$$\begin{bmatrix} \psi_s^s \\ \psi_r^s \end{bmatrix} = \begin{bmatrix} L_s & L_m \\ L_m & L_r \end{bmatrix} \begin{bmatrix} i_s^s \\ i_r^s \end{bmatrix} \quad (8)$$

For the simulation diagram, the system of equations describing the coaxial generator is built in the static reference coordinate axis system $\alpha\beta$. Where the α axis coincides with the axis of the phase a stator winding.

The inputs are stator and rotor voltages converted to the same static coordinate axis $\alpha\beta$

$$\begin{cases} v_{\alpha s}^s = \frac{2}{3}(v_{as} - \frac{1}{2}v_{bs} - \frac{1}{2}v_{cs}) = \frac{2}{3}v_{as} - \frac{1}{3}v_{bs} - \frac{1}{3}v_{cs} \\ v_{\beta s}^s = \frac{2}{3}(\frac{\sqrt{3}}{2}v_{bs} - \frac{\sqrt{3}}{2}v_{cs}) = \frac{1}{\sqrt{3}}v_{bs} - \frac{1}{\sqrt{3}}v_{cs} \end{cases} \quad (9)$$

To convert the rotor voltage to the same static coordinate axis $\alpha\beta$ attached to the stator is done through two steps as follows:

First: Perform the conversion of the rotor voltage abc to the static coordinate axis associated with the rotor itself using the conversion formula as for the stator

$$\begin{cases} v_{\alpha r}^r = \frac{2}{3}v_{ar} - \frac{1}{3}v_{br} - \frac{1}{3}v_{cr} \\ v_{\beta r}^r = \frac{1}{\sqrt{3}}v_{br} - \frac{1}{\sqrt{3}}v_{cr} \end{cases} \quad (10)$$

Second: Since the rotor is rotating relative to the stator, then perform the rotational conversion of rotor voltage quantities in the first step to the same static reference coordinate axis $\alpha\beta$ attached to the stator, the conversion angle θ_r :

$$v_r^s = v_r^r e^{j\theta_r}$$

$$\begin{cases} v_{\alpha r}^s = v_{\alpha r}^r \cos\theta_r - v_{\beta r}^r \sin\theta_r \\ v_{\beta r}^s = v_{\alpha r}^r \sin\theta_r + v_{\beta r}^r \cos\theta_r \end{cases} \quad (11)$$

$$\theta_r(t) = \int_0^t \omega_r(t) dt + \theta_r(0)$$

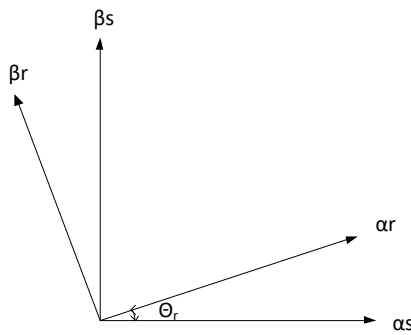


Figure 1. Vector schema converted from rotor to stator

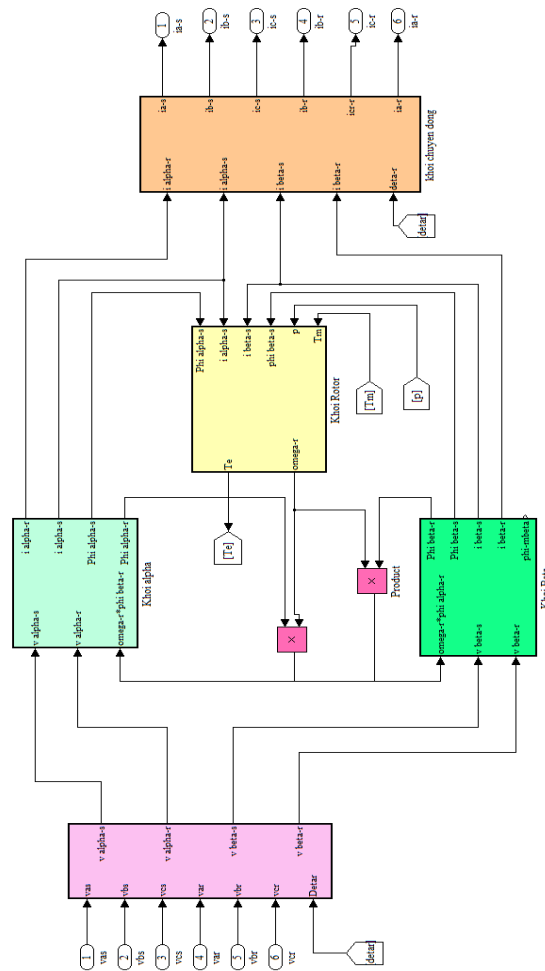


Figure 2. Coaxial transmitter system in $\alpha\beta$ reference coordinate axis system

3. EXPERIMENTAL

Because the power at the generator output changes with the velocity of the main machine, when connecting the generator to the grid, it can cause a number of problems such as power fluctuations, voltage stability, sometimes even affecting power quality.

Therefore, the goal of adjusting the power of the transmitter is to control the power of the transmitter closely following the set signal. At the same time, the control is independent between the acting power and the reactive power of the generator.

$$\begin{cases} i_{\alpha s} = -\frac{L_r}{L_\sigma} \psi_{\alpha s} + \frac{L_m}{L_\sigma} \psi_{\alpha r} \\ i_{\beta s} = -\frac{L_r}{L_\sigma} \psi_{\beta s} + \frac{L_m}{L_\sigma} \psi_{\beta r} \\ i_{\alpha r} = \frac{L_m}{L_\sigma} \psi_{\alpha s} - \frac{L_r}{L_\sigma} \psi_{\alpha r} \\ i_{\beta r} = \frac{L_m}{L_\sigma} \psi_{\beta s} - \frac{L_r}{L_\sigma} \psi_{\beta r} \end{cases} \quad (12)$$

$$H_1 = \begin{bmatrix} \frac{L_s}{L_m} & -\frac{R_s}{L_s} \\ \frac{R_s}{\omega_s L_m} & \frac{L_s}{L_m} \end{bmatrix} \quad (17)$$

$$H_2 = \begin{bmatrix} 0 & -1 \\ \frac{1}{\omega_s L_m} & 0 \end{bmatrix} \quad (18)$$

We have the vector variable states of the rotor current and stator as follows:

$$\begin{cases} \frac{di_{\alpha s}}{dt} = \frac{L_m}{L_\sigma} u_{\alpha r} - \frac{L_r}{L_\sigma} u_{\alpha s} + \frac{R_s L_r}{L_\sigma} i_{\alpha s} - \frac{R_r L_m}{L_\sigma} i_{\alpha r} - \omega_r L_m \frac{L_r i_{\beta r} + L_m i_{\beta s}}{L_\sigma} \\ \frac{di_{\beta s}}{dt} = \frac{L_m}{L_\sigma} u_{\beta r} - \frac{L_r}{L_\sigma} u_{\beta s} + \frac{R_s L_r}{L_\sigma} i_{\beta s} - \frac{R_r L_m}{L_\sigma} i_{\beta r} + \omega_r L_m \frac{L_r i_{\alpha r} + L_m i_{\alpha s}}{L_\sigma} \\ \frac{di_{\alpha r}}{dt} = \frac{L_m}{L_\sigma} u_{\alpha s} - \frac{L_s}{L_\sigma} u_{\alpha r} - \frac{R_s L_m}{L_\sigma} i_{\alpha s} + \frac{R_r L_s}{L_\sigma} i_{\alpha r} + \omega_r L_s \frac{L_r i_{\beta r} + L_m i_{\beta s}}{L_\sigma} \\ \frac{di_{\beta r}}{dt} = \frac{L_m}{L_\sigma} u_{\beta s} - \frac{L_s}{L_\sigma} u_{\beta r} - \frac{R_s L_m}{L_\sigma} i_{\beta s} + \frac{R_r L_s}{L_\sigma} i_{\beta r} - \omega_r L_s \frac{L_r i_{\alpha r} + L_m i_{\alpha s}}{L_\sigma} \end{cases} \quad (13)$$

The output signal of the generator is determined as the acting power and the reactive power on the stator. They can be determined by the stator current and voltage as follows:

$$\begin{bmatrix} P_{s_ref} \\ Q_{s_ref} \end{bmatrix} = \begin{bmatrix} u_{\alpha s} & u_{\beta s} \\ u_{\beta s} & -u_{\alpha s} \end{bmatrix} \begin{bmatrix} i_{\alpha s_ref} \\ i_{\beta s_ref} \end{bmatrix} \quad (14)$$

Thus, the stator current can be determined:

$$\begin{bmatrix} i_{\alpha s_ref} \\ i_{\beta s_ref} \end{bmatrix} = \frac{1}{u_{\alpha s}^2 + u_{\beta s}^2} \begin{bmatrix} u_{\alpha s} & u_{\beta s} \\ u_{\beta s} & -u_{\alpha s} \end{bmatrix} \begin{bmatrix} P_{s_ref} \\ Q_{s_ref} \end{bmatrix} \quad (15)$$

Rotor current value according to the stator signal and stator power:

$$\begin{bmatrix} i_{\alpha r_ref} \\ i_{\beta r_ref} \end{bmatrix} = \frac{H_1}{u_{\alpha s}^2 + u_{\beta s}^2} \begin{bmatrix} u_{\alpha s} & u_{\beta s} \\ u_{\beta s} & -u_{\alpha s} \end{bmatrix} \begin{bmatrix} P_{s_ref} \\ Q_{s_ref} \end{bmatrix} + H_2 u_s \quad (16)$$

In which the values H1, H2 are determined as follows:

- PID-FUZZY controller:

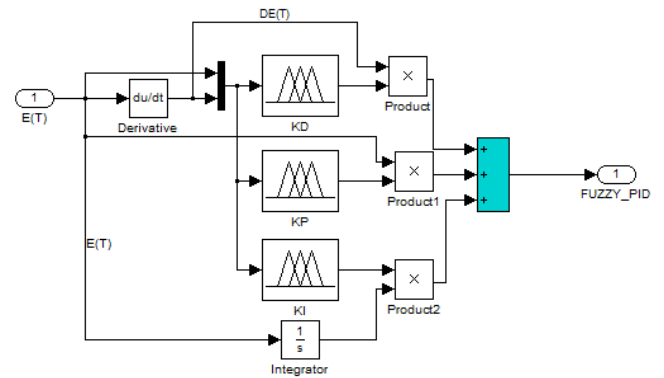


Figure 3. PID-FUZZY controller

Formulation of constituent laws:

IF ... THEN

The law governs kp:

Kp	DET							
	N31	N21	N11	ZE	P11	P21	P31	
ET	N3	U	U	U	U	U	U	
	N2	M	L	L	L	L	M	
	N1	S	M	L	U	L	S	
	ZE	Z	S	M	L	M	Z	
	P1	S	M	L	U	L	S	
	P2	M	L	L	U	L	M	
	P3	U	U	U	U	U	U	

Governing Law Kd:

Kd/Ki	DET							
	N31	N21	N11	ZE	P11	P21	P31	
ET	N3	Z	Z	Z	Z	Z	Z	Z
	N2	M	S	S	Z	S	S	M
	N1	L	M	S	Z	S	M	L
	ZE	U	L	M	S	M	L	U
	P1	L	M	S	Z	S	M	L
	P2	M	S	S	Z	S	S	M
P3	Z	Z	Z	Z	Z	Z	Z	

De-blurring according to the focus method.

4. RESULTS AND DISCUSSION

Independent control scheme of applied power and reactive power of coaxial generators using dual power heterogeneous power machines:

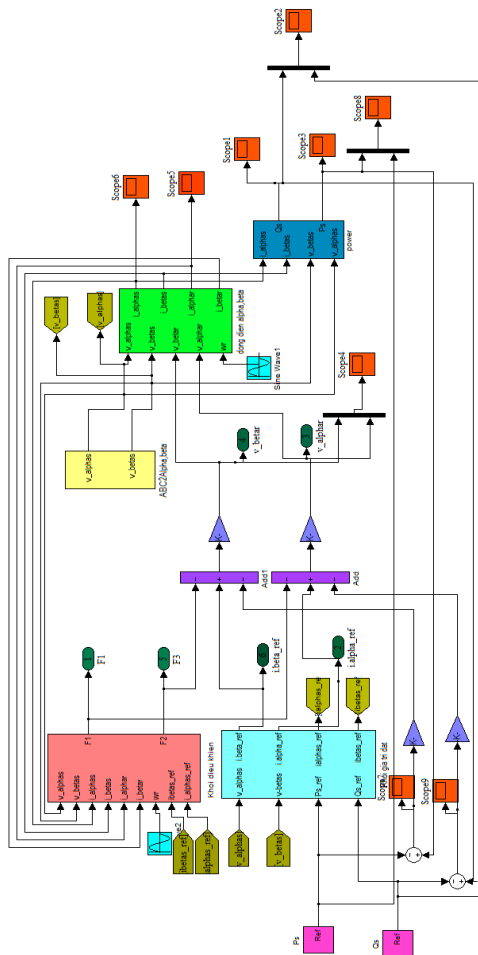


Figure 4. Diagram of stabilization of applied power and reactive power stator terminal reactive power coaxial generator using Fuzzy logic



Figure 5. Fuzzy logic control signal generation block

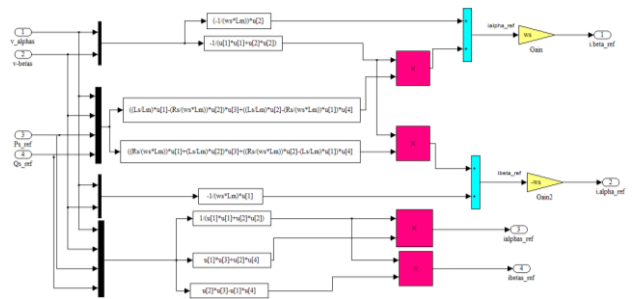


Figure 6. Set value block

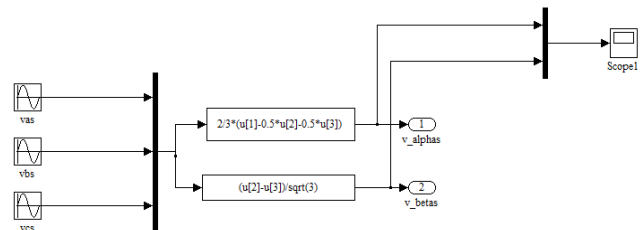


Figure 7. ABC to Alpha, beta transfer block



Figure 8. Alpha and beta current detector

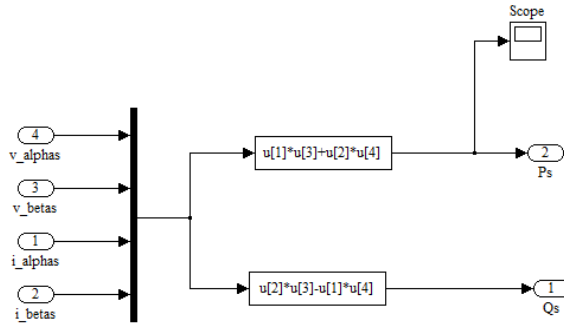


Figure 9. Power block

The simulation was conducted on Matlab/Simulink software. To perform the simulation, we choose and use a three-phase asynchronous generator, the winding rotor and have the parameters as shown in the table below:

Table 1. Parameters of the system

Moment of inertia	$J = 0.32 \text{ kgm}^2/\text{s}^2$
Rated speed	$n=1440\text{rpm}$
Current frequency	$f=50\text{Hz}$
Rated power	$P=3.6\text{MW}$
Rated stator voltage	$220/380\text{V}(\Delta/Y)$
Number of polar pairs	$2p=4$
Stator resistor	$R_s = 0.0079 \Omega$
Rotor resistance	$R_r=0.025 \Omega$
Rotor inductance	$L_{lr}=0,4\text{H}$
Stator inductance	$L_{ls}=0,7937\text{H}$
Magnetized inductance	$L_m=4.4\text{H}$

Substituting the above parameters into the equation we get:

- Stator winding wire inductance:
 $L_s = L_{ls} + L_m = 0.7937 + 4.4 = 5.1937 \text{ H}$

- Inductance of rotor winding wires converted to stators :
 $L_r = L_{lr} + L_m = 0.4 + 4.4 = 4.8\text{H}$

- Total dissipation coefficient:
 $L_\sigma = 1 - \frac{L_m}{L_s L_r} = 0.2234\text{H}$

The value set for the two components of acting power and reactive power.

- Interval from 0 to 4.5s, the set value for the effective capacity is 2.1MW

- The period from 0 to 3.5s set for reactive power is 0 MVAR

- The interval from 4.5s to 5s set for the effective capacity is increased from 2.1MW to 3.6MW

- Interval from 3.5s to 4s the set value for resistance capacity is increased from 0 to 3000MVAR

- Interval from 7.5s to 8s set for audience capacity

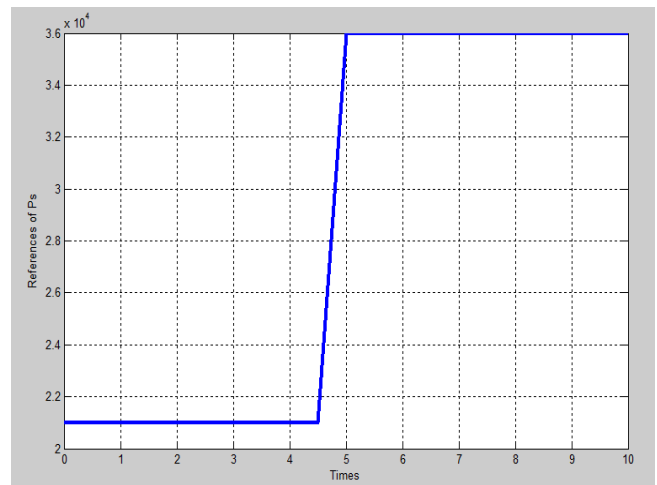


Figure 10. Ps power set value

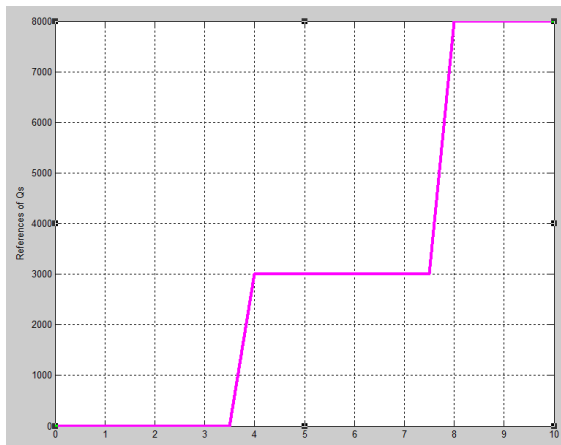


Figure 11. Power setting value Q_s

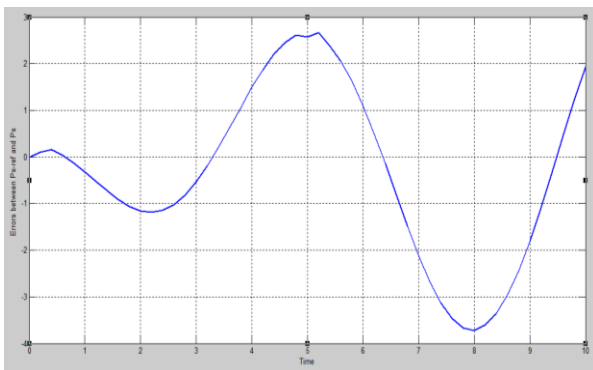


Figure 12. Error between power set value P_s -ref and P_s in the presence of fuzzy logic control

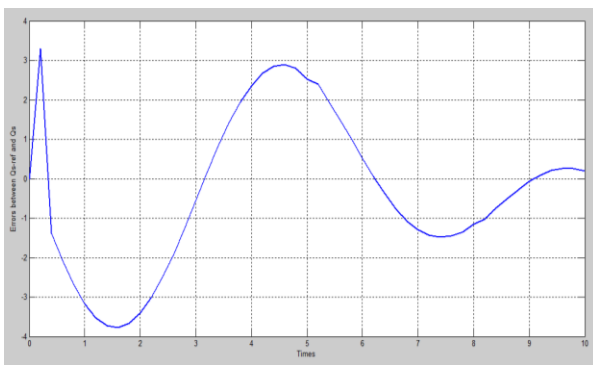


Figure 13. Error between power set value Q_s -ref and Q_s in the presence of fuzzy logic control

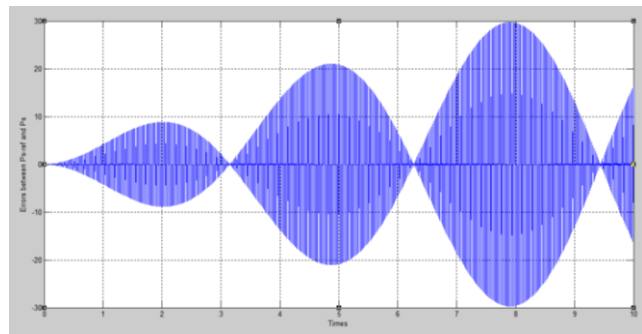


Figure 14. Error between power set value P_s -ref and P_s with PID-Fuzzy control

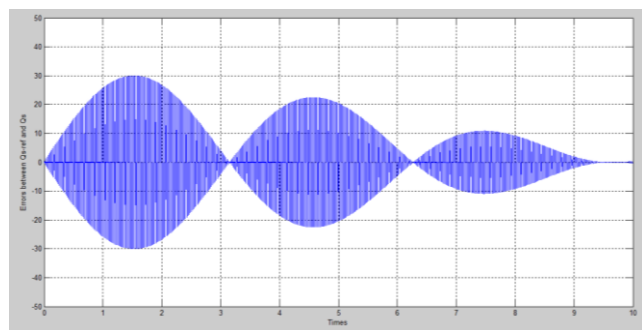


Figure 15. Error between power set value Q_s -ref and Q_s with PID-Fuzzy control

Observe:

The angular speed of the transmitter rotor varies with the sine waveform and is considered as interference acting on the transmitter system. The variable angular velocity makes the power P_s and Q_s unstable:

Case 1:

When there is no dimming controller, the power of P_s and Q_s of the generator is unstable according to the setting signal the jump is very large

Case 2:

When there is a PID-Fuzzy controller, the power of P_s and Q_s of the transmitter is stable according to the set signal the error between the set power and the power of the generator is small

Case 3:

When there is a dimming controller, the output Ps and Qs power of the transmitter is stable according to the set signal the error between the set power and the power of the emitted generator is very small.

5. CONCLUSION

Simulation results in all three cases with Fuzzy Logic controller, PID-Fuzzy controller and no controller show that the Fuzzy Logic controller for coaxial generators is stable to the power of the transmitter. The outstanding advantage of this controller is that when there is a change in the speed of the transmitter, the output power remains stable compared to the preset power and the Fuzzy controller gives a much smaller error than PID-Fuzzy

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