Speed Control System of the Generator with the Radial Magnetic Coupling Using Second Order Model

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Abstract—The Radial Magnetic Coupling (RMC) is the connected device of the automatic transmission by controlling the power of magnetic coil in order to adjust round speed as needed. The Radial Magnetic Coupling system is non-linear model that make it difficult to design the control system. This paper proposed a sample design for the speed control of the generator with the RMC using second order model. The speed control system with the PI Controller can maintain the speed of the generator that has disturbance such as variable speed outer rotor and load efficiency.

Keywords—radial magnetic coupling; second order model; system identification; PI controller

I. INTRODUCTION

The generator's performance should be controlled speed and torque of the rotor. The wind turbine generator used the transmission system to control the speed and torque of the generator. To optimize the power of the wind turbine generator, it must be able to with the wind speed [1]. in order to improve the radial magnetic coupling (RMC) and reduce parasitic loss of transmission or application for industries. Yao et al [2] studied the torque, material, distance of the magnetic coupling between radial magnetic gears. Montague, Bingham and Atallah considered the analysis and application of magnetic gearbox and magnetic coupling technologies and issues surrounding their use of the motion control servo systems [3-4]. The advantage of electromagnetic clutch water pump in vehicle engine cooling system can be reduced fuel consumption [5]. Chakravarthi et al [6] are designed a robust PI controller for a second order system plus delay (SOSPD) which has an inherent nonlinearity by the virtue of its structural dynamics. Yoo, Kwak and Lee proposed an identification method to estimate the second order time delay (SOPTD) model parameters. The proposed method directly obtains these parameters using a frequency-weighted integral transform and a least-squares method [7]. Pongamg et al [8] investigated the mathematical model via system identification and optimized controller for reheating furnace walking hearth type.

This paper develops simple speed control system of the generator with the RMC using second order model. PI controller design is applied by using Signal-Constraints of MATLAB/Simulink program. The experimental and simulation results can be effective on controlled speed of the

generator in 600–800 rpm range. The case studies are considered disturbances such as speed outer rotor in 2000 - 3000 rpm range and load.

II. CONTROL SYSTEM DESIGN

A. Control System Diagram

The control system diagram is considered the speed control of the generator such as wind turbine generator. The inner rotor is connected to the generator and outer rotor is connected to motor with closed-loop speed control acting as variable wing speed turbine. The RMC is used to coupling and decoupling between outer and inner rotor functioning as transmission system in wind turbine generator. This research demonstrates speed control system diagram of the generator with the RMC as shown in Fig I. The one side of the generator is connected to the inner rotor of the RMC. The objective of the control system must be constant speed control of the generator (ω_{out}) with the RMC. The $G(s)$ is the second order model according to the RMC. The PI-controller has a transfer function $G_c(s)$ as

$$G_c(s) = K_p + \frac{K_i}{s} \quad (1)$$

Where K_p is the controller is proportional gain, K_i is the integral controller

FIGURE I. CONTROL SYSTEM DIAGRAM OF THE RMC

where, ω_{ref} is the speed of inner rotor reference of the generator, ω_s is the speed of outer rotor from motor, ω_{out} is the speed of inner rotor of the generator, I_{RMC} is the current of the RMC and T_L is the load of the generator.

B. Mathematical Modeling of the RMC

The radial magnetic coupling (RMC) is consisted of outer rotor and inner rotor, as shown in Figure II. The outer rotor is made of steel material that attaches to the shaft of the prime motor power as an input (ω_s) to the inner rotor. To excite coil in inner rotor, it generates excited magnetic field. Main parameters of the RMC are shown in Table I.

FIGURE II. RADIAL MAGNETIC COUPLING

TABLE I. PARAMETERS OF THE RMC

Parameter	value	unit
Outer rotor outside diameter	100	mm
Inner rotor outside diameter	96	mm
Inner rotor coil resistance	2	Ω
Pole of inner rotor	8	pole

The nature of the radial magnetic coupling (RMC) is complex system and non-linear model. The dynamics of this system can be described by the second order equation via linearization technique. The transfer function between input (I_{RMC}) and output (ω_{out}) can be obtained

$$G(s) = \frac{K\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2} \quad (2)$$

where K is the static gain, ω_n is the natural frequency and ζ is the damping ratio.

III. EXPERIMENTAL AND SIMULATION RESULTS

This section consists of the experimental setup and dynamic responses of the control system.

A. Experimental Setup

Figure III shows experimental setup of the speed control system of the generator with the RMC. The inner rotor part of the RMC consists magnetic coil of 8 poles. The current of the RMC ranges from 0 -16 amp at 12 voltage. The magnetic field creates an attraction to the inner and outer rotors in order to rotate together. The speed outer rotor (ω_s) of the RMC is controlled by closed-loop PI controller. The generator with the RMC includes the generator, speed sensor, DC motor and microcontroller interface to computer. The signals linked to computer and board which is an electronic board functioning as a device linking between computers with the experimental

equipment through serial cable to PCI serial card of computers.

FIGURE III. EXPERIMENTAL SETUP

B. System Identification of Second Order Model

First of all, the relationship between input and output responses in range of linear model must be investigated. The speed outer rotor (ω_s) has 2000-3000 rpm range which is related to the speed inner rotor's 600-800 rpm range. The mathematical model of the generator with the RMC can be estimated by measuring speed inner rotor (ω_{out}) and current of the RMC (I_{RMC}) using Parameter Estimation of MATLAB/Simulink program. The parameters of the model is shown in Table II.

TABLE II. PARAMETERS OF SECOND ORDER MODEL

	Parameter		
	K	ζ	ω_n
value	21.6628	1.1829	1.2133

The speed responses of the generator with the RMC are compared between the model and experiment as shown in Fig. IV. The result revealed that the parameter estimation of the second order model and speed inner rotor was accorded in 600-800 rpm range.

FIGURE IV. SPEED RESPONSES OF THE GENERATOR WITH THE RMC

C. Optimaization PI Contoller

The parameters of PI controller can be determined by using Signal-constraints of MATLAB/Simulink program. Parameter and functional constraints limits the maximum overshoot 20%, Rise time < 0.2 sec and Setting time < 7.5 sec. The result of this program defined is shown in Table III.

TABLE III. PARAMETERS OF PI CONTROLLER

	Parameter	
	K_p	K_i
value	0.2806	0.0792

D. Experiment Results

The speed control of the generator with the RMC can be examined by an experimental design. The experiments have three cases with regard to variable input reference and perturbing system.

FIGURE V. SPEED OUTER ROTOR RESPONSE

FIGURE VII. CURRENT PROFILE OF THE RMC

FIGURE VIII. HARMONIC SPEED OUTER ROTOR

FIGURE VI. SPEED INNER ROTOR RESPONSES WITH STEP INPUT

FIGURE IX. SPEED INNER ROTOR RESPONSES

First case of an experiment insists to variable step input (ω_{ref}) with constant speed outer rotor (ω_s) as shown in Figure V and Figure VI. The current profile (I_{RMC}) depends on the PI controller to step input as shown in Figure VII. The step

input changes in range from 600 - 800 rpm and speed inner rotor response (ω_{out}) accords to variable step input.

Second case, the speed outer rotor (ω_s) is the harmonic $\omega_s(t) = 2500 - 500\cos\omega t$ rpm and $\omega = 0.25$ rad/sec as shown in Figure VIII. The speed inner rotor reference (ω_{ref}) is constant speed at 700 rpm and the current profile is shown in Figure X. The speed inner rotor (ω_{out}) control responses can

efficiently maintain speed with disturbance such as harmonic outer rotor as shown in Figure IX.

FIGURE X. CURRENTS PROFILE OF THE RMC

FIGURE XI. HARMONIC SPEED OUTER ROTOR

FIGURE XII. LOAD PROFILE

Third case the disturbances are applied to inner rotor speed that variable the outer rotor speed and load from the generator. The speed outer rotor (ω_s) has a harmonic of $\omega_s(t) = 2500 - 500 \cos \omega t$ rpm and $\omega = 0.25$ rad/sec as shown in Figure XI. The load profile (T_L) is shown in Figure XII. Under these conditions, the control of inner rotor speed at 700 rpm can be efficiently maintained with disturbance as shown in Figure XIII. The current control (I_{RMC}) is the compensated

power to the magnetic field of the inner rotor with the disturbances acting on the control system as shown in Figure XIV. Examining the resulting response, the inner rotor's speed seems to settle out near the reference of 700 rpm.

FIGURE XIII. SPEED INNER ROTOR RESPONSES WITH LOAD

FIGURE XIV. CURRENTS PROFILE OF THE RMC WITH LOAD

IV. CONCLUSION

The mathematical model of the generator with the RMC can be estimated by second order model and compared to the experimental data by parameter estimation which can be used to design PI controller. The results of an experiment demonstrated that the proposed speed control with PI controller is efficient to control the inner rotor speed with 600-800 rpm range and its outer rotor variable speed with 2000-3000 rpm range and of 0-1 watt load.

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