A control of wound-rotor induction generator for random wave input generation system

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Abstract—This paper deals with the secondary excited induction generator applied to random wave input generation system. As it is preferred to stabilize the output voltage and frequency in the constant level, microcomputer controlled CSI connected to the secondary windings supplies the secondary current with slip frequency. For testing this method, the input torque simulator is constructed, according to the power flow analysis. The experimental and numerical results show the advantage of secondary excited induction generator system for the random input wave generation system.

Index Terms—Random wave input generation system, wound type induction generator, sea wave.

I. INTRODUCTION

The present days, due to the world energy crisis, the natural energy source, such as the wind or wave energy, has become developed intensively, because this kind of energy is considered as the 'clean' and 'rich' one. It is significant especially for the countries which have little fossil fuel. But from the utility point, this natural energy is hardly used because it is random one. This means that the output power from the natural energy source always fluctuates statistically and the stabilizable controller is indispensable in the actual applications

This paper proposes one strategy to get the Constant Voltage Constant Frequency(CVCF) output power from the natural energy source using secondary excited induction generator. To keep the output frequency constant, the microcomputer controlled current source inverter (CSI) is applied to the system.

This method is considered to be superior to the conventional synchronous generator-rectifier-inverter set from the view point of saving the KVA capacity of the power converter.

The basic structure of the control contains the secondary current control and the frequency stabilizer, which need smaller energy capacitance. The secondary current control by CSI can keep the output voltage constant and the frequency stabilizer can maintain the output frequency constant and these operations also valid in regenerative mode.

These procedures are carried out in the 8-bit microprocessor where the delta modulation is employed to keep the voltage constant. Experimental results show the validity of the proposed strategy.

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II. A GENERAL ANAYSIS OF THE RANDOMLY VARING NATURAL POWER INPUT GENERATION SYSTEM

As it is well known, the energy of nature can be considered as random one, so there is still much left to be studied hereafter for the improvement of system efficiency and the general utility.

For that purpose, the model should reflect the determination of the rating and electro-mechanical elements. To overview the total system generally, the basic strategy for the random input generation system should be constructed. The statistic analysis can become the strong tool to find out the control method because the real-sized experiment can be omitted .

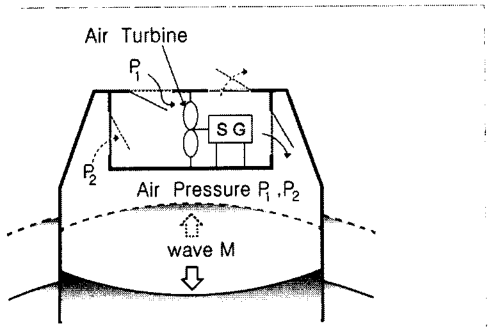
This method is based on the power spectrum analysis from the input to output waveform. By the total analysis using above method, all the variables, including the inaccessible or the unseen variables, in the total power flow, can be reproduced in the computer simulation. This step is convenient for the feasible study or random input generation.

If the relation between one energy conversion stage(#i) and the following stage(#j) is treated to be linear, the following equation is satisfied,

$$S_{\#j}(\omega) = H(\omega)\cdot H^{*}(\omega)\cdot S_{\#j}(\omega) = |H(\omega)|^{2}\cdot S_{\#i}(\omega) \quad (1)$$

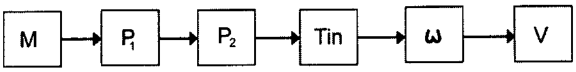
where, $S\ (\omega)$ represents the power spectrum density and $H(\omega)$ represents the transfer function in the frequency domain.

Here, the sea wave generation is analyzed so that the secondary excited induction generation system can be applied. When this analysis is applied to the sea wave generation, where the air turbine is used for driving the induction generator, the following power flow diagram holds. [5] Fig. 1 shows the structure of the sea wave input generation system and the simplified power flow diagram. Where, SG means synchronous generator.



(a)

M: sea wave, P1: air pressure, P2: air pressure, Tin:



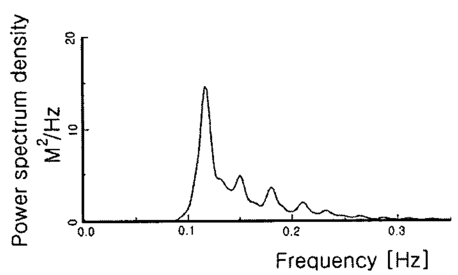
torque into turbine, ω: rotational speed, V: output voltage

(b)

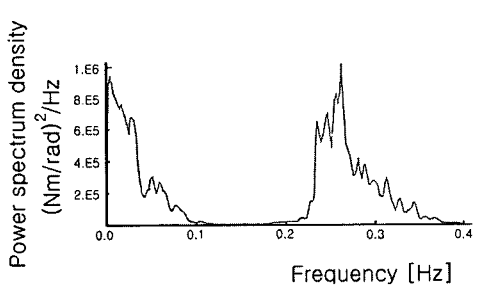
Fig. 1 Structure(a) and power flow diagram(b) of the sea wave input generation system

In each stage, the approximated transfer function is defined, from the measured power spectrum density.

In Fig. 2(a), the spectrum density of sea wave is shown in the experiment on the sea.[1]-[4] Fig. 2(b) shows the air turbine torque, which is to drive the induction generator. This power spectrum density which can not be measured directly, is reproduced by the computer calculation.



(a)



(b)

Fig. 2 The power spectrum density of the sea wave generation system (a) sea wave of experiment (b) torque into air turbine

These figures show the validity of this analysis based on the statistic method. As well as these results, the waveform In any stage can be reproduced and utilized for the random input generation system. [6]-[10]

In the later example, the torque of air turbine is simulated by the separately excited dc motor driven by statistically controlled PWM chopper. Induction generator is adapted in place of the synchronous generator because of CVCF generation.

III. THE CONTROL PRINCIPLE OF GENERATOR AND ITS POWER FLOW

These analysis help the control design of secondary excited induction generation system for the CVCF generation, From reviewing Fig. 2(b), simple delta modulation technique can become utilized in the control system because the main power spectrum density is concentrated in relatively low frequency.
The delta modulation is suitable for the microcomputer control because this technique is based on the simple incremental or decremental action.

Fig. 3 shows a schematic sectional view of induction generator.

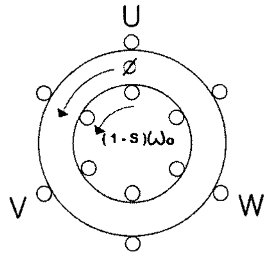


Fig. 3 A schematic sectional view of induction generator

When the speed of rotor is $(1-s)\cdot f/p$ [rps] and the secondary winding is excited at sf [Hz], the speed of the main flux become the sum of the both speed as follows ,

$$sf/p+(1-s)f/p=f/p \qquad (2)$$

Where s means the slip number and p means the number of poles.

In other words, secondary winding is excited in negative and positive phase sequence at supersynchronous and subsynchronous state respectively.

When the secondary winding is excited according to the equation(2), the output frequency of primary can be kept constant in spite of the variation of the rotor speed. In this case, the equivalent circuit shown in Fig. 4, can be applied.

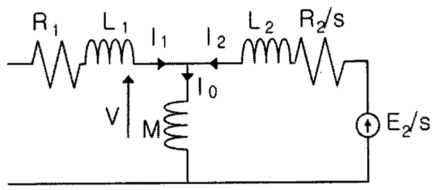
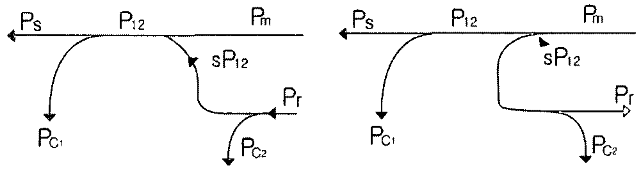


Fig. 4 The equivalent circuit of secondary excited induction generator

Therefore the power flow at the supersynchronous and subsynchronous speed should be represented in Fig. 5 (a), (b) respectively.



(a) at supersynchronous speed (b) at subsynchronous speed

Fig. 5 The power flow at super- and subsynchronous speed of the rotor

If the driving power from the air turbine (or the other alternative device) to the generator is defined as P_m, then the transmitted power $P_{12} = P_m/(1-s)$ is accordingly greater than the input power at subsynchronous speed. The secondary power source, provides the power $P_r = sP_{12}$ in addition to the total secondary losses P_{c_2}, where P_{c_2} includes the losses in the rotor resistance and losses in the CSI. And the output power becomes $(P_{12} - stator\ losses)$. In supersynchronous operating, the situations are turned .

Secondary excited induction generator system for random input, can be simulated experimentally as show in Fig. 6.

Here the separately excited dc motor simulates the air turbine. The output torque from dc motor is made by the signal, which represents the statistically varied input torque and is synthesized through the shaping filter. In the later experiment, the power spectrum density of this simulator is determined after the experimental results done in the sea. [1]-[3]

As shown in Fig. 6 the current-fed inverter is adopted as a controlled current source in the secondary circuit of the machine. The other advantages the current source inverter is the regenerative operating mode. Thus it can control the power flow into, or out of, the secondary circuit as required. Moreover the output frequency can be maintained in constant level by the control of firing angle. Both controls are realized easily by the employment of microcomputer .

IV. CVCF OUTPUT POWER CONTROL

The output voltage is controlled according to dc link current I_d, when the load is constant. To keep the output voltage constant, the firing angle of the three phase full bridge thyristor rectifier determined on the basis of the delta modulation technique. The command of the firing angle from the microcomputer by the delta modulation is 'incremental' or 'decremental' action according to the difference between the detected value and the reference value of the dc link current. As the

time constant of random Input is generally far larger than the sampling time employed in the controller, the simple delta modulation technique is applicable to the control of the output voltage. Here the 'incremental' command can advance the firing angle by one unit which is already determined in the program. In the 'decremental' action, the firing angle decreases by one unit.

Thus the firing angle from 0 to 180 can be covered including regenerative operating mode. This strategy is applied to the determination of the slip frequency control by the CSI. In this case, at first, the reference slip frequency is determined from the difference between the reference synchronous speed and the detected rotor

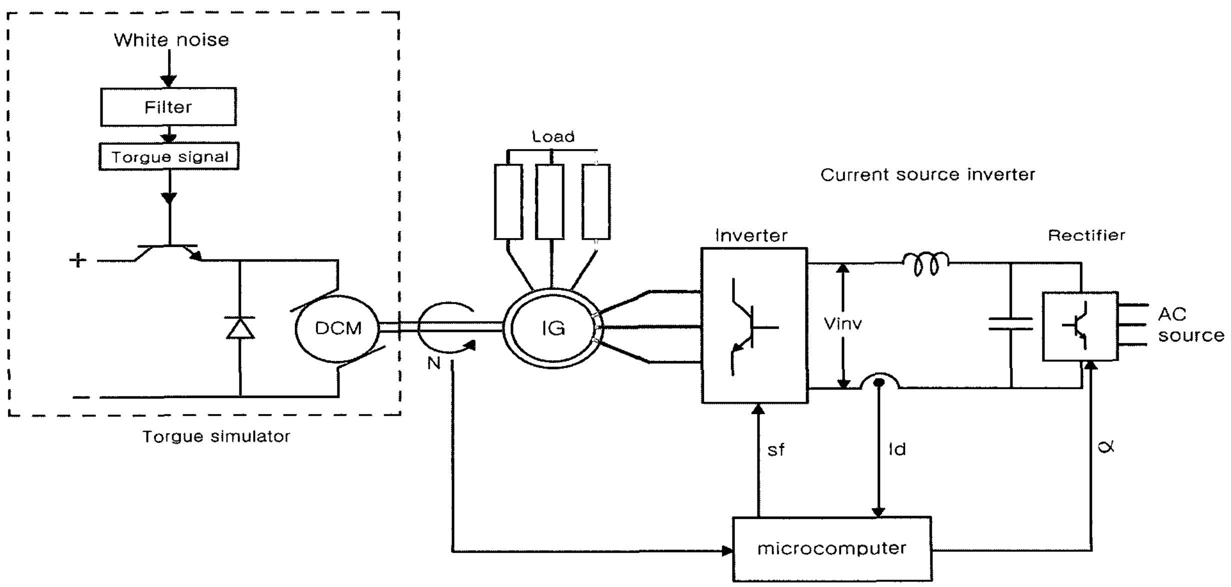
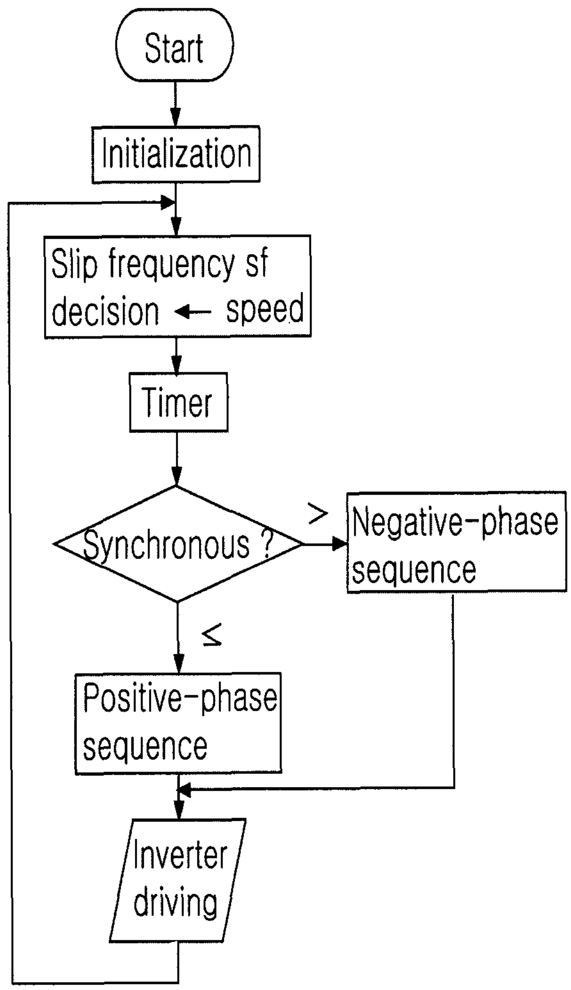


Fig. 6 The schematic total generation system

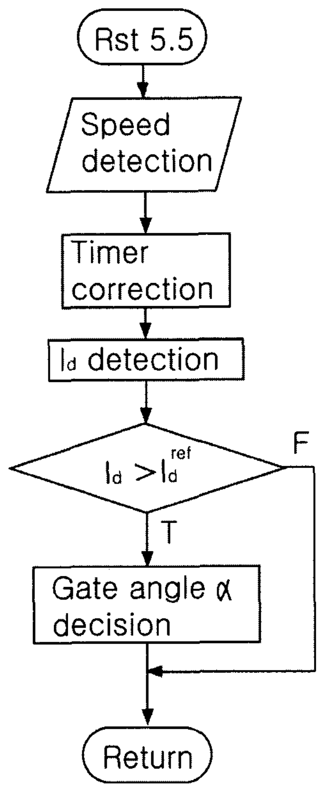
speed. By comparing this reference slip frequency with the former slip frequency, which is just the reference slip frequency in the last stage, the action of the increment or the decrement of one unit is chosen. Both control methods are easy for the microcomputer programming and requires the small memory capacitance.

V. EXPERIMENTAL HARDWARE AND RESULTS

The digital control of the power converts requires suitable interface circuits between the CPU and the power stages. Here the some peripheral chips are used for that purpose. The flow chart is shown in Fig. 7. In the main program, the slip frequency is determined and at the incremental mode the dc link current is controlled.



(a) main



(b) interrupt routine

Fig. 7 The flow charts of the control algorithm

In the experiment, 4-poles, 2.8[KVA], wound induction generator and 2-poles, 2[kw] dc motor are used in the laboratory. The nameplate parameters of both machines are shown in Table 1.

Table 1 The ratings of wound induction generator and dc motor which are used in the experiments

1) Separately excited dc motor

ratings		constants of circuit	
output power	2 kw	Ra	3.36 Ω
poles	2 poles	Ke	0.622 Vs/rad
armature current	20 A		
field current	0.62 Amp		

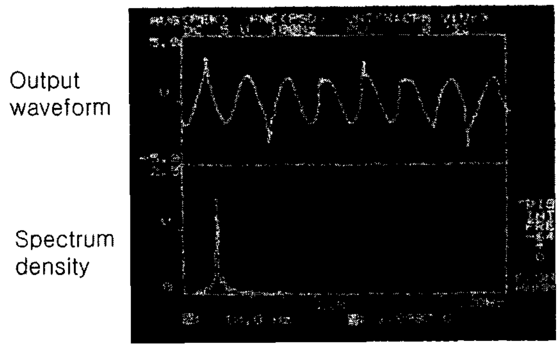
2) Wound induction generator

ratings		constants of circuit	
output power	2.2 kw	R_1	0.776 Ω
poles	6 poles	R_2	1.030 Ω
primary current	13 Amp	L_1	3.11 mH
primary voltage	200 V	L_2	3.11 mH
secondary current	9.7 A	M	33.69 mH
secondary voltage	137 V	a	1.38

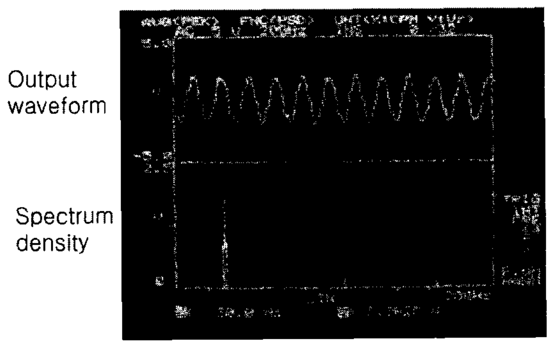
During experiment, the random input torque simulator is connected to this secondary excited induction generator. Here, the random input torque simulator is based on the air turbine torque from the sea wave motions. Therefore the results can correspond with the sea wave generation system using the proposed method.

Fig. 8 shows the power spectrum density of the output voltage. The main spectrum density is kept on the determined synchronous speed, and the harmonics are well suppressed. This shows the validity of the delta modulation technique.

Fig. 9 shows the rms value of the output voltage. The rms value is measured by the rms converter equipment. This figure also shows the effectiveness of the delta modulation. These two figures point out that the secondary excited induction generation applied to the randomly varying input power is effective for the CVCF generation under the proposed control strategy.



(a) output voltage frequency 10[Hz] synchronous speed 300[rpm]



(b) output voltage frequency 30 [Hz] synchronous speed 900[rpm]

Fig. 8 Experimental example of the output voltage and its power spectrum density

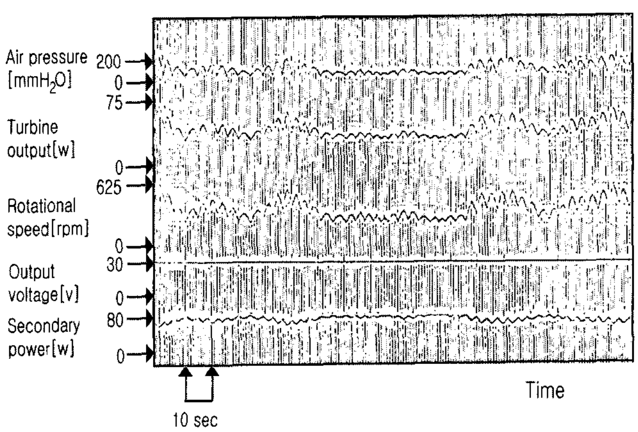


Fig. 9 Experimental example of time response (Id=1.65A, Rload=20Ω,Ns=900rpm)

VI. CONCLUSIONS

In the random input generation system, in which the input and output wave form is already given, the numerical model of the energy conversion system can be constructed based on the power flow analysis. As this method can be applied to general random input system, the energy conversion system can be easily simulated and experimented. In this case, the secondary excited induction generator is suitable because the CVCF generation is possible.

The delta modulation technique makes the implementation of the control easy with the microcomputer system. The experimental results, which corresponds to the sea wave generation system, show the validity of this statistical approach of the system analysis and control.

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