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POD Based Vector Control of SCIG in a Point Absorber Wave Energy Conversion System

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***Abstract*—Wave Energy has proved to be an important renewable energy resource around the globe. Different types of devices have been constructed and are still being designed to extract the wave energy optimally. The paper discusses on the vector control technique to control a Squirrel Cage Induction Generator to generate the wave power. In order to reduce the oscillations in the generated power the concept of a POD controller is introduced. The point absorber based wave energy converter utilizing the SCIG to generate wave power is implemented in MATLAB/Simulink Platform. Modelling of the point absorber buoy and the vector control technique with POD is discussed. The results are discussed in comparison with the conventional PI controller.**

Keywords—Wave Energy Converter, Point Absorber Buoy, Indirect vector control, Power Oscillation Damper (POD).

I. INTRODUCTION

Ocean energy has found be to a significant and reliable source of renewable due to its availability, and predictability which is 24x7. Compared to other forms of renewable energy such as the wind energy and solar, it has more power density and it can also travel farther distances without losing energy. The world potential of ocean energy is found to be in the order of 1TW. Different technologies have been developed for wave energy extraction. They can be classified according to the direction of waves, location of the converters, i.e. whether on shore, near shore or offshore, according to the power take off systems and operating principles. Point Absorber Buoy is a wave energy converter that is found to be more reliable as it is independent on the direction of the incident waves, and also because of its compactness [3]. The electrical machine used for generating the electrical power from the wave power can be linear generators or rotary generators. As linear generators exhibit underutilization of the energy, rotary generators were chosen. Squirrel Cage Induction Generators (SCIG) was selected for the work discussed in this paper, as it was seen as a better choice compared to the Permanent Magnet Synchronous Generator (PMSG). This is because it is of less cost, its robustness and also it requires less maintenance. The oscillating linear motion of the buoy is converted to the rotary motion through a rack and pinion gear arrangement [2].

The oscillating nature of the waves, results in variations of the mechanical torque and hence the speed of the rotating generator. To keep the machine speed in track with the oscillating buoy, the Vector control technique is seen as a suitable choice. This enhances a continuous and reliable power generation [1]. The concept of Power Oscillation Damper Controller is used as the controller in the vector control strategy. As its name suggests, the controller enhances the damping of the power oscillations of the SCIG. The waveforms while using the conventional PI controller is also discussed to observe the comparison with that of POD controller.

II. POINT ABSORBER BASED WAVE ENERGY CONVERSION SYSTEM

The proposed system is described as shown in the Fig.1. At a standstill condition, the buoy simply floats, and the generated power is zero. When a wave hits the buoy, it oscillates vertically in a heave motion. This vertical oscillation is converted to the rotary motion by the rack and pinion gear arrangement. The rotating gear causes the rotation of the SCIG.

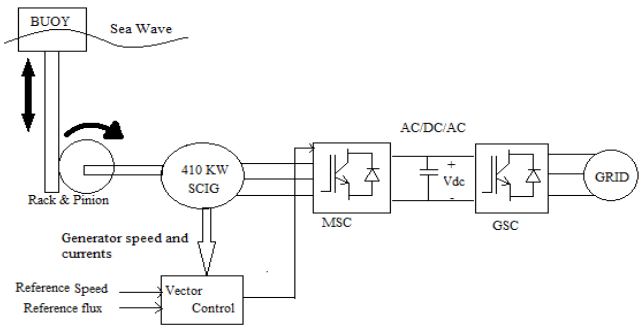


Fig.1. Block Diagram of the Point Absorber Based WEC System

The generator generates the electric power which is dispatched to a grid through back to back AC-DC converters. The machine side converter provides the necessary excitation to the SCIG, and the grid side converter maintains the dc link voltage, and supplies the required power to the grid even when the speed of the buoy is zero and no power is generated [2].

A. Modeling of the Point Absorber buoy.

Point Absorber buoy is a type of wave energy converter that oscillates upon the incidence of ocean waves from any direction [3]. It is located offshore, usually along with more other similar point absorber buoys and the power generated from them is dispatched to the grid through underwater cables. The system implemented in this paper has a high power point absorber buoy of about 866kW [2]. A mass spring damper system is used to model the dynamics of the point absorber buoy as shown in Fig.2.

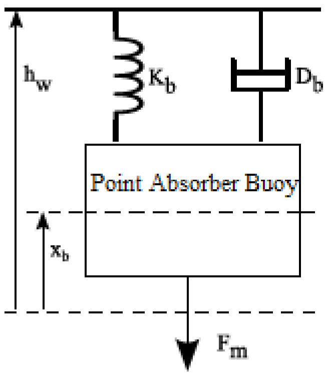


Fig.2 Mass Spring Damper representation of the Buoy.

The equation of Newton's second law of motion can be used to model the buoy [2].

$$M_b x_b + D_b (\dot{x}_b - \dot{h}_w) + K_b (x_b - h_w) = - F_m \quad (1)$$

$$T_m = K_c F_m \quad (2)$$

$$K_b = A_b \rho g \quad (3)$$

Where, h_w is the height of the wave, x_b is the buoy displacement from an equilibrium, K_b is the spring constant proportional to area of the buoy A_b, density of the water ρ, and gravitational constant g, Mb is the mass of the buoy, D_b is the damping constant, F_m is the reaction force of the generator, T_m is the mechanical torque, and K_c is the gear ratio. The equation that also considers the gear and the generator shaft coupling is given by;

$$2H \frac{d\omega_r}{dt} = T_m - K_{sh}\theta_{ag} - D_{sh}(\omega_{by} - \omega_r) \quad (4)$$

Where, ω_r is the generator speed, ω_{by} is the speed of the buoy, θ_{ag} is the Shaft tensional twist angle, H is the Inertia of the buoy, K_{sh} is the shaft stiffness, and D_{sh} is the shaft damping constant [4].

B. Modeling of the Vector Control with POD controller

Vector Control is a technique that is used to control the machine speed and torque, by maintaining the air gap flux at a constant level thus controlling the armature and field parts of the induction machine separately as similar to that in dc drives [1]. This technique promises a good dynamic response. The oscillating nature of ocean waves is a challenge in producing uninterruptable electric power. So this again necessitates the use of vector control technique, which controls the flux, in magnitude, frequency and phase. This helps the electric machine to be in track with the oscillating buoy. The generator torque can catch up with the varying speeds of the buoy. The implementation of the vector control is as shown in the Fig.3. The control scheme is termed as Indirect vector control as it does not use any sensors. The generator speed ω_r, stator currents i_{abc}, reference flux λ_r^*, and reference speed ω_{ref} are taken as inputs, to produce the stator dq current commands i_{qs}^* and i_{ds}^*. These currents are converted to i_{abc}^* and compared with i_{abc} to produce the gate pulses to machine side converter [1].

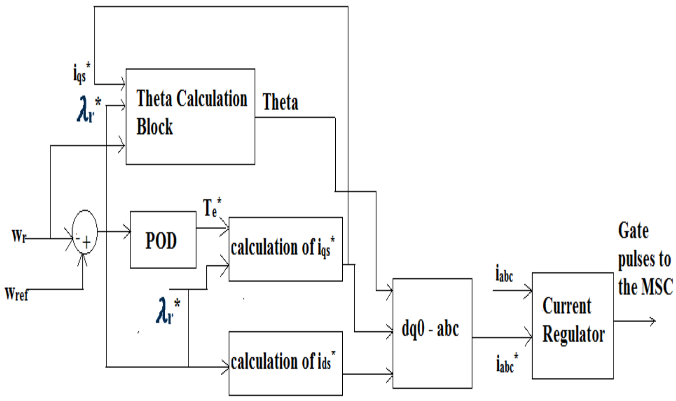


Fig.3. Block Diagram of Vector Control Implementation

The equations used for the calculations are given by;

$$i_{ds}^* = (1 + T_r\, p)\frac{\lambda_r^*}{L_m} \quad (5)$$

$$T_r = L_r / R_r. \quad (6)$$

$$i_{qs}^* = \left(\frac{2}{3}\right)\left(\frac{2}{p}\right)\left(\frac{T_e^*}{\lambda_r^*}\right)\left(\frac{L_r}{L_m}\right) \quad (7)$$

$$\omega_{sl} = \left(\frac{L_m}{T_r}\right)\left(\frac{i_{qs}^*}{\lambda_r^*}\right) \quad (8)$$

$$\theta_f = \int (\omega_r + \omega_{sl})\, dt. \quad (9)$$

Where, T_r - Time Constant, R_r – Rotor Resistance, L_r – Rotor Self Inductance, ω_{sl} - slip speed, L_m-mutual inductance, θ_f -field angle (theta) and T_e^* is the reference torque.

The reference torque is generated by the controller. The controller takes in the error signal produced from the generator speed and the reference speed, as its input. PI controller has been used widely to generate the active power as in . However reduction of oscillations was still a concern. Power Oscillation Damper controller is a power system stabilizer, the concept which has been implemented in wind power generation schemes and has achieved significant reduction in the generated power oscillations.

The general concept is as shown in the Fig.4.POD controller consists of a gain block, a washout filter, and a phase compensation block. The washout block is a high pass filter. The signal output is added with a reference value and passed through a limiter to produce the desired value. The use of phase compensators in POD controller has been avoided in the simulation of the WEC system, as there was not much difference in using it [6].

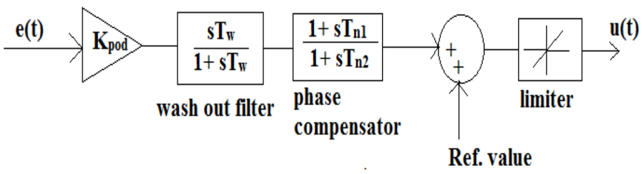


Fig.4. Block Diagram of a POD Controller

III. SIMULATIONS, RESULTS AND DISCUSSIONS

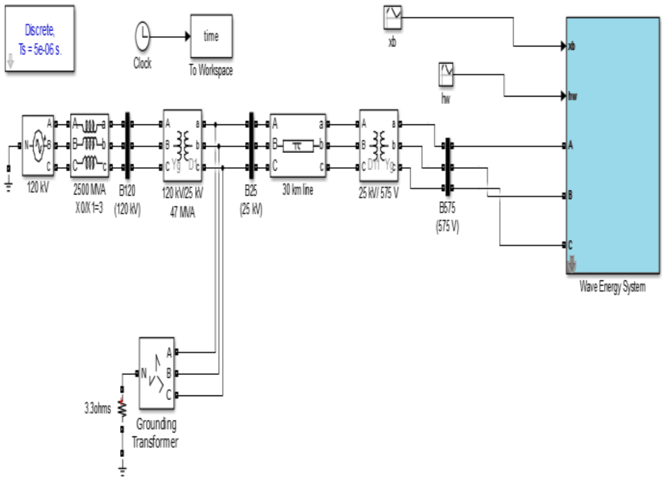


Fig.5. Simulink Model of the WEC system connected to the grid.

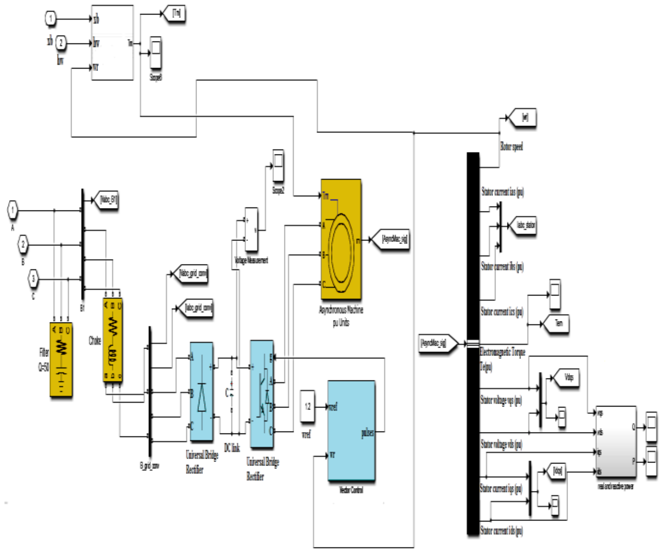


Fig.6. Subsystem of the WEC system

Fig.5 and Fig.6 shows the Simulink models of the point absorber based wave energy conversion system. The WEC system is connected to a 120kV grid [5]. The power generated is transferred to the grid through the AC-DC back to back converters. Fig.7. shows the Simulink model of the vector control of the SCIG.

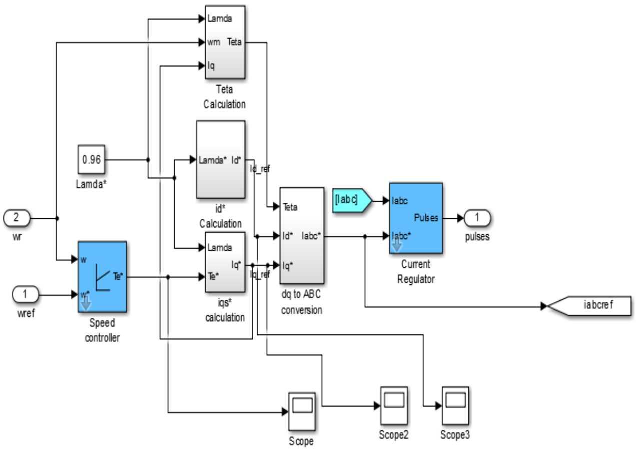


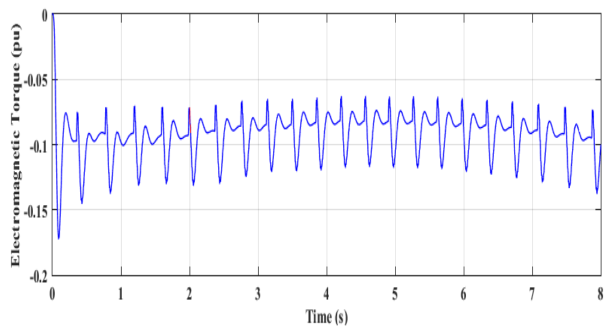
Fig.7. Simulink model of the vector control

The Table 1, shows the parameters used for modeling. The parameters while using PI controller is also mentioned.

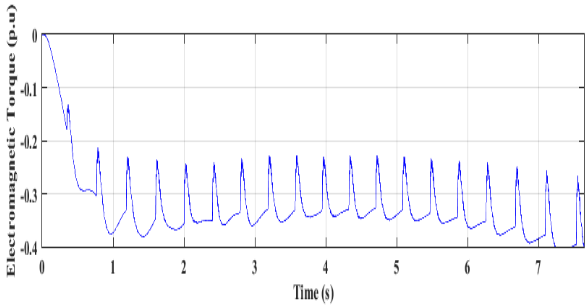
TABLE 1 Parameters of Vector Control

Reference speed ω_{ref}	1.2 p.u
Reference Flux λ_r*	0.96 p.u
Proportional Gain K_p	13
Integral Time constant T_i	26
Gain K_{pod}	29.5
Time constant of washout filter T_w	5.2

The models were simulated in MATLAB Simulink and the waveforms obtained for the speed , torque and the active power generated by the SCIG is shown below. The results are compared to that obtained while a PI Controller was used. Fig 7(a) and 7(b), shows the electromagnetic torque of the SCIG while using PI and POD respectively, and there is a reduction the oscillations when POD controller was used. A similar observation can be seen with the speed waveforms shown in Fig. 9(a) and 9(b). The speed waveforms when using the POD controller has reduced offsets from the reference value. The generated power waveforms shown in Fig. 8(a) and 8(b) also has a significant difference in the oscillations. The oscillations are about 67% when using PI and controller and it has reduced to 3.33% when POD controller was used.

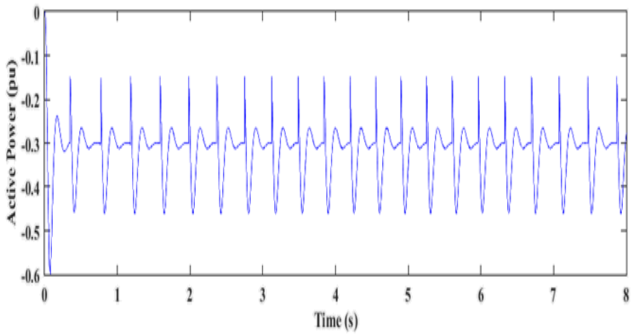


7(a)

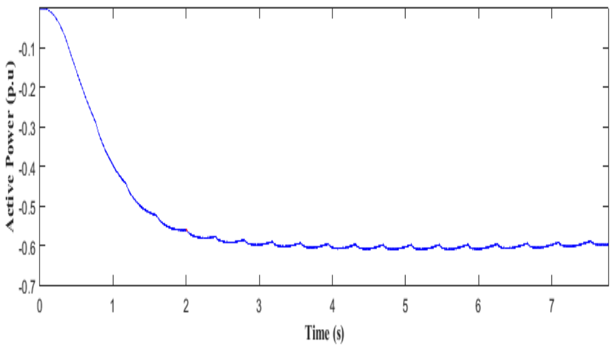


7(b)

Fig.7 Electromagnetic Torque of SCIG when using (a)PI and (b) POD controller

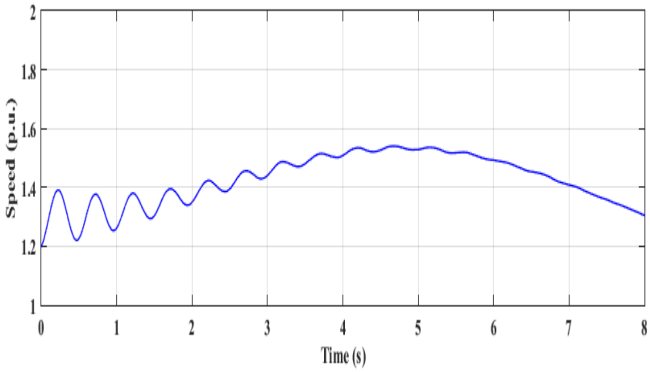


8(a)

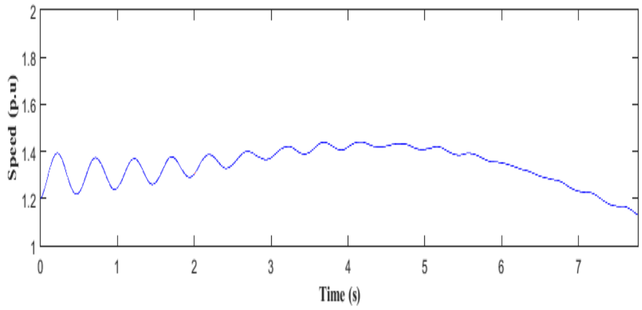


8(B)

Fig.8. Active Power Generated when using (a) PI and (b) POD controller



9(a)



9(B)

Fig.9. Speed of the SCIG when using (a)PI and (b) POD controller

IV. CONCLUSION

A point absorber based Wave energy converter was modeled in the MATLAB/Simulink software. Squirrel Cage Induction Generator was used as the electrical machine for power generation. The vector control technique used to control the SCIG has enabled the machine speed to be in track with the varying torque of the oscillating buoy using the PI controller, but the presence of oscillations could not be eliminated. The concept of POD controller has bought a significant oscillation reduction. Further reduction in oscillations of the power generated may be possible by using FACTS devices, as applied to wind generation units.

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