A Robust PI Controllers for Tidal Current Turbine Based on Doubly Fed Induction Generator for Improving Power System Stability

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ABSTRACT

Tidal current energy is one of the most rapidly growing renewable technologies for generating electric power. Doubly Fed Induction Generators (DFIG) and Direct Drive Permanent Magnet Synchronous Generators (DDPMSG) are the most commonly used generators with tidal current turbines. The aim of this work is to analyze a typical configuration of a tidal turbine driving a doubly fed induction generator (DFIG) and propose PI controllers for the grid side converter and generator side converter for improving the stability of the overall system under different conditions. The overall system is tested for small disturbances using the proposed PI controllers. The analytical and the simulation results illustrate the robustness of the proposed PI controllers for improving the power system stability.

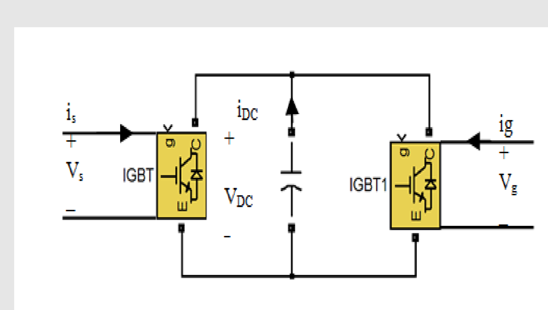
DYNAMIC MODELING OF TIDAL CURRENT TURBINE

- The speed signals (resource) model $T_m = \frac{0.5\rho\Pi R^2 C_p v_{tide}^3}{w_t}$
- Rotor model $2H_t\frac{d\omega_t}{dt} = T_m - T_e - D_m\,\omega$, $\omega_t = \omega/p,$
- Dynamic modeling of the generator

$$v_{ds} = -R_s\, i_{ds} + X'\, i_{qs} + e_d$$
$$v_{qs} = -R_s\, i_{qs} - X'\, i_{ds} + e_q$$
$$\frac{de_d}{dt} = -\frac{1}{T_0}\left(e_d + (X - X')i_{qs}\right) + s\,\omega_s e_q - \omega_s \frac{L_m}{L_{rr}} v_{qr}$$
$$\frac{de_q}{dt} = -\frac{1}{T_0}\left(e_q - (X - X')i_{ds}\right) - s\,\omega_s e_d + \omega_s \frac{L_m}{L_{rr}} v_{dr}$$
$$e_d = -\frac{\omega_s L_m}{L_{rr}}\psi_{qr} \quad and \quad e_q = \frac{\omega_s L_m}{L_{rr}}\psi_{dr}.$$

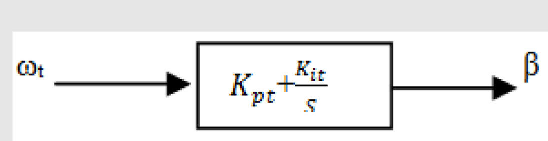
- The converters model

$$P_s + P_g + P_{DC} = 0$$
$$P_{DC} = v_{DC} i_{DC} = C v_{DC}\frac{dv_{DC}}{dt}$$
$$P_g = v_{Dg} i_{Dg} + v_{Qg} i_{Qg}$$



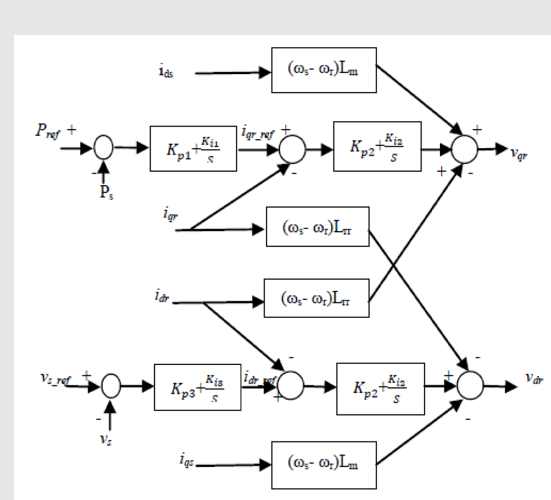
- The pitch controller model

$$\beta = \left(K_{pt} + \frac{K_{it}}{s}\right)\omega_t$$
$$\frac{d\beta}{dt} = K_{pt}\frac{d\omega t}{dt} + K_{it}\omega_t$$



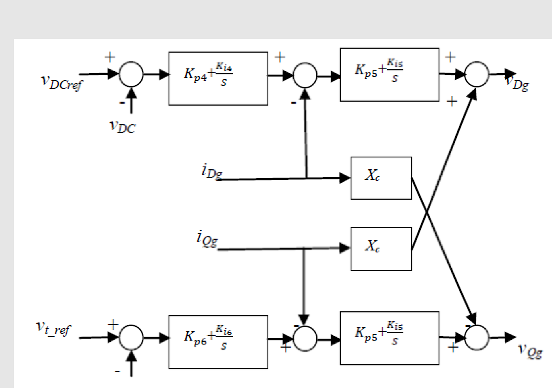
- The generator side converter controller model

$$\dot{x}_1 = P_{ref} - P_s$$
$$\dot{x}_1 = -K_{i1}/K_{p1}x_1 + 1/K_{p1}\, i_{qr\ ref}$$
$$\dot{x}_2 = i_{qr\ ref} - i_{qr}$$
$$\dot{x}_2 = K_{p1}\dot{x}_1 + K_{i1}\, x_1 - i_{qr}$$
$$\dot{x}_2 = -K_{i2}/K_{p2}x_2 + 1/K_{p2}\, v_{qr} - \omega_s L_m/K_{p2}\, i_{ds} - \omega_s L_{rr}/K_{p2} i_{dr} + (L_m/K_{p2})\, i_{ds}\omega_r + (L_{rr}/K_{p2}) i_{dr}\omega_r$$
$$\dot{x}_3 = v_{s\ ref} - v_s$$
$$\dot{x}_3 = -K_{i3}/K_{p3}x_3 + 1/K_{p3}\, i_{dr\ ref}$$
$$\dot{x}_4 = i_{dr\ ref} - i_{dr}$$
$$\dot{x}_4 = -K_{i2}/K_{p2}x_4 + 1/K_{p2}\, v_{dr} - \omega_s L_m/K_{p2}\, i_{qs} - \omega_s L_{rr}/K_{p2} i_{qr} + (L_m/K_{p2})\, i_{qs}\omega_r + (L_{rr}/K_{p2}) i_{qr}\omega_r$$



- The grid side converter controller model

$$\dot{x}_5 = v_{DC\ ref} - v_{DC}$$
$$\dot{x}_6 = K_{p4}\dot{x}_5 + K_{i4}x_5 - i_{Dg}$$
$$\dot{x}_7 = v_{t\ ref} - v_t$$
$$\dot{x}_8 = K_{p6}\dot{x}_7 + K_{i6}x_7 - i_{Qg}$$
$$v_{Dg} = K_{p5}\dot{x}_6 + K_{i5}x_6 + X_c i_{Qg}$$
$$v_{Qg} = K_{p5}\dot{x}_8 + K_{i5}x_8 - X_c i_{Dg}$$



STATE SPACE REPRESENTATION AND SYSTEM EIGENVALUES

In this section we formulate the state space representation of the whole system and study the small signal stability analysis of a single machine infinite bus system for tidal current turbine using DFIG with and without controllers. Small signal stability is the ability of the power systems to remain in synchronism under small disturbances. Small signal stability analysis for the power system determines the properties of operation of the system due to small disturbance in the system. This is done by finding the eigenvalues of the system for a small change that may have happened. In this section we perturb each state of the system by a small increment keeping in mind some assumptions. These assumptions are: $\Delta^2=0$, $\sin\Delta=0$ and $\cos\Delta=1$.

$$\dot{x} = Ax + Bu$$
$$, x = [w_t, \beta, v_{DC}, \Theta_{tr}, e_d, e_q, V_{DC}, x_1, x_2, x_3, x_4, x_5, , x_6, x_7, x_8]^T$$
$$, u = [v_{ds}, v_{qs}, i_{dg}, i_{qg}]^T.$$
$$\Delta\dot{x} = A\Delta x + B\Delta u$$
$$, \Delta x = [\Delta w_t, \Delta\beta, \Delta v_{DC}, \Delta\Theta_{tr}, \Delta e_d, \Delta e_q, \Delta V_{DC}, \Delta x_1, \Delta x_2, \Delta x_3, \Delta x_4, \Delta x_5, \Delta x_6, \Delta x_7, \Delta x_8]^T$$

Table (1) Eigen values without controllers

Eigen Value	Real part (σ)	Imaginary part (ω)	Freq. (Hz)
λ_1	-8	-	-
λ_2	-1500	-	-
λ_3	-0.05	+j100	15.9
λ_4	-0.05	-j100	15.9
λ_5	-2	+j3	0.48
λ_6	-2	-j3	0.48
λ_7	-1179	-	-

Table (2) Eigen values with controllers

Eigen value	Real part (σ)	Imaginary part (ω)	Freq. (Hz)
λ_1	-10	-	-
λ_2	-1542.9	-	-
λ_3	-1	+j50	7.96
λ_4	-1	-j50	7.96
λ_5	-2	+j3	0.48
λ_6	-2	-j3	0.48
λ_7	-1444	-	-
λ_8	-100	-	-
λ_9	-27	-	-
λ_{10}	-175	-	-
λ_{11}	-27	-	-
λ_{12}	-10	-	-
λ_{13}	-8	-	-
λ_{14}	-10	-	-
λ_{15}	-27	-	-

Table (3) Preferred range of the controllers coefficients values

Proportional Controllers Coefficients Range			Integral Controllers Coefficients Range		
Coefficient	Max	Min	Coefficient	Max	Min
K_{p1}	200	0.002	K_{i1}	99999	0.5
K_{p2}	16	0.00009	K_{i2}	29999	0.2
K_{p3}	438	0.003	K_{i3}	12499999	0.7
K_{p4}	17	0.0009	K_{i4}	299999	0.2
K_{p5}	200	0.009	K_{i5}	999999	5
K_{p6}	240	0.009	K_{i6}	1499999	8

Table (1) shows the eigenvalues of the system without controllers and table (2) shows the eigenvalues with controllers. As the values of the controllers coefficients change, the stability will change. We try to change the values of the coefficients independently and try to find the preferred range of the controllers values for the system stability as in table(3).

C0NCLUSION

- The use of tidal currents as a new source of energy is a very effective source as it relies on the same technologies used in wind turbines and it is a predictable source of energy.
- Tidal current turbines without controllers do have the capability to sustain a small disturbance for a long period. Using PI controllers with the tidal current turbine increase the stability margin.
- The preferred ranges of values of the controllers coefficients for the stability of the system are concluded for both types of machines used for this work.

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