Feedback Resonating Controller For a Heaving Point Absorber WEC

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ABSTRACT

The optimal feedback control law for a wave energy converter (WEC), namely complex conjugate (CC) control, is known to be acausal, meaning that it cannot be physically implemented without future knowledge of the incoming wave forces. However, one of the assumptions in the derivations of the CC controller is that it allows the device to resonate and absorb the maximum amount of power at all frequencies, that is on the entire interval $f \epsilon [0, \infty)$, where f is the wave frequency. In practice, however, for every location in the sea, the large majority of the power transported by waves is concentrated in a limited frequency band, and the tuning of the optimal controller for all frequencies is unnecessary.

This work presents the design and implementations of a simple, stable, and causal Feedback Resonating Controller (FBR) that approximates the response of the CC controller in a limited frequency band. By making the limited bandwidth assumption, simulation results show that the FBR controller is able to absorb more than 95% of the power absorbed by the CC controller in the desired interval $f \epsilon [0.25,\ 0.95]\, Hz$, without requiring information about incoming waves; the only required measurement is the velocity of the buoy.

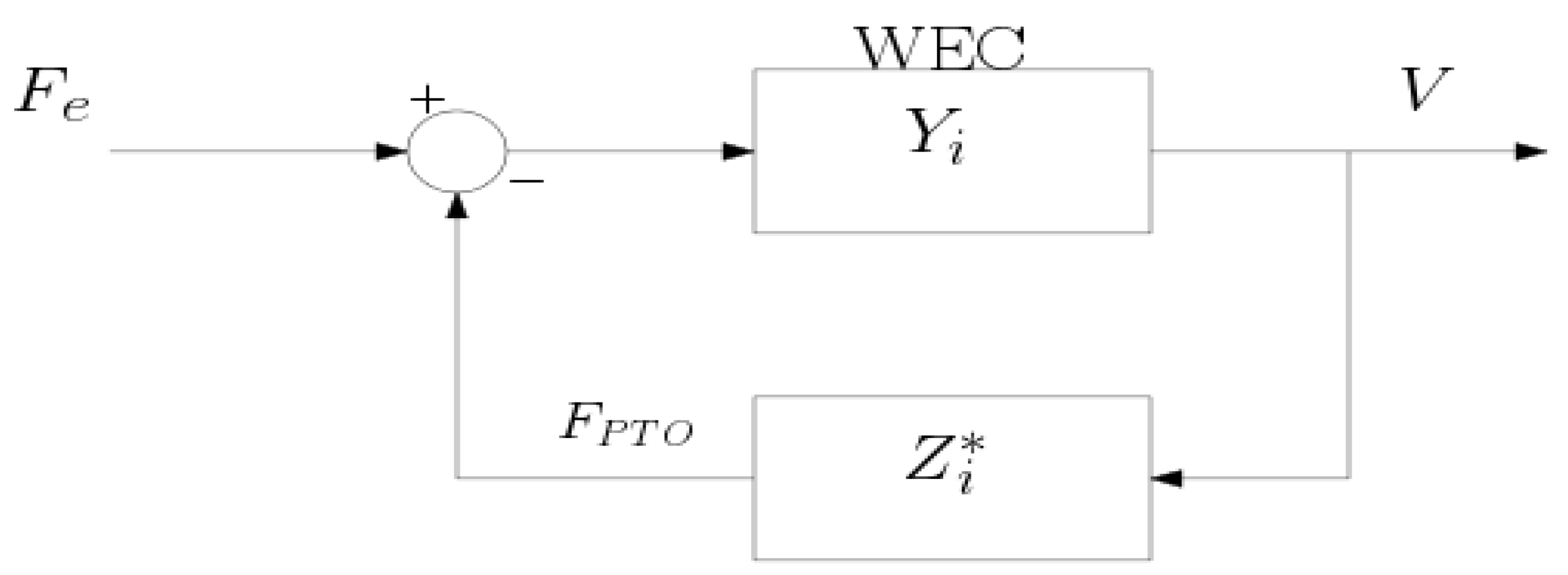

Figure 1: Complex Conjugate Controller

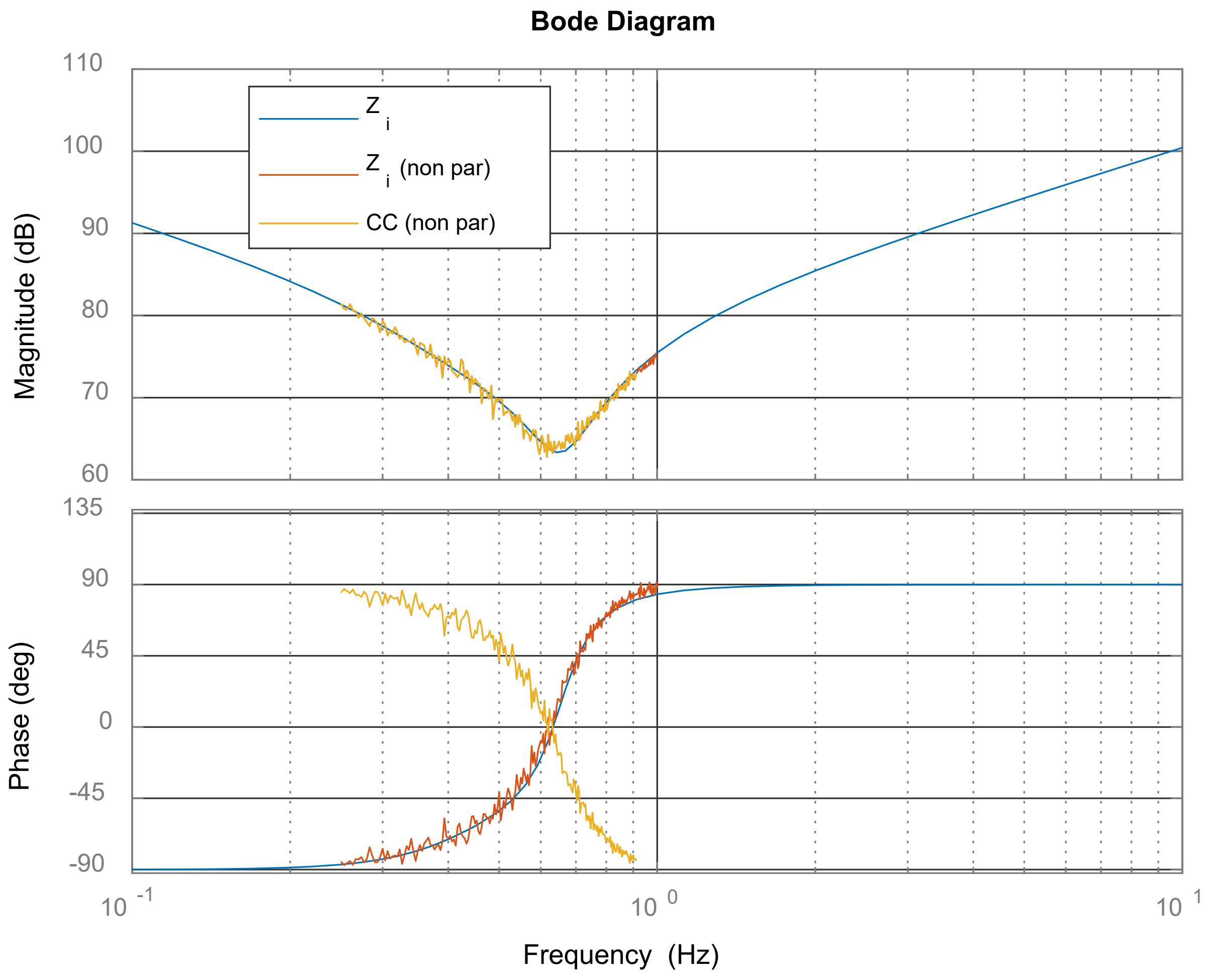

Figure 2: Bode plot of the impedance and its complex conjugate

Complex Conjugate Control

Complex Conjugate control is a feedback control scheme in which the controller calculates, at every time instant, the optimal PTO force to be applied in order to maximize the power absorbed by the WEC. Figure 1 shows the block diagram of the complex conjugate control, where F_e denotes the excitation force, V denotes the buoy’s velocity, F_{PTO} is the force applied by the Power Take Off (PTO), and the WEC is described by its intrinsic admittance Y_i [1]. The optimal feedback provided by the CC control is the complex conjugate of the intrinsic impedance Z_i of the device (hence the name “complex conjugate”), where $Z_i = {Y_i}^{-1}$. The CC control allows the WEC to absorb the maximum amount of power, which is given by the formula:

$$W_{PTO}, MAX = \frac{1}{2\pi} \int_0^\infty \frac{|F_e|^2}{2R_i} d\omega\,,$$

where R_i is the intrinsic resistance, that is the real part of the intrinsic impedance [1].

The CC controller, however, cannot be implemented in practice because it is not causal, which means that its impulse response is non-zero for $t < 0$. In fact, by defining the impulse response from the mechanical impedance as the following:

$$h(t) = K(t) - S\sqrt{\pi/2}sgn(t),$$

where $K(t)$ is the causal part of the impulse response of the impedance, it can be observed that when $t < 0$ then $h(t) = S\sqrt{\pi/2} \neq 0$.

Feedback Resonating Controller

The objective is to design a feedback controller that has the same structure as the one described in Figure 1, and that provides a causal approximation to the CC control in a limited range of frequencies. The frequency range can be selected as the one where most of the wave power occurs for a given site. The derivation and implementation of such controller (the FBR) is demonstrated using experimental data collected at the Maneuvering and Sea Keeping (MASK) basin, located at Naval Surface Warfare Center, Carderock Division (NSWCCD), using Sandia’s heaving point absorber [2]. Figure 2 shows the Bode plot of the intrinsic impedance of the WEC; in particular, both parametric (blue) and non-parametric (red) models are plotted. In the same diagram is also plotted the optimal feedback (complex conjugate of Z_i), which is obtained by inverting the phase response (red curve). The FBR is designed by fitting the optimal non-parametric response with a parametric model; this process is carried out by means of system identification (SID). Figure 3 shows the optimal non parametric feedback (marked with red stars) overlapped with the causal and stable parametric model resulting from SID. Figure 4 shows the simulation results of the FBR when compared with the CC; in particular the top plot shows the normalized absorbed power, calculated as the power absorbed for a unitary excitation force at all frequencies. The bottom plot shows the ratio of the absorbed power: it can be seen that the FBR is capable of absorbing between more than 95% of the theoretical maximum power, provided by the CC, across a wide frequency range. It should be noted that the frequency range is for a small scale device; if the device is considered to be a at a 1:17th scale, the FBR controller is capable of absorbing more than 95% of the theoretical maximum for waves with period in the range $4.4 \leq T \leq 16.5\, s$.

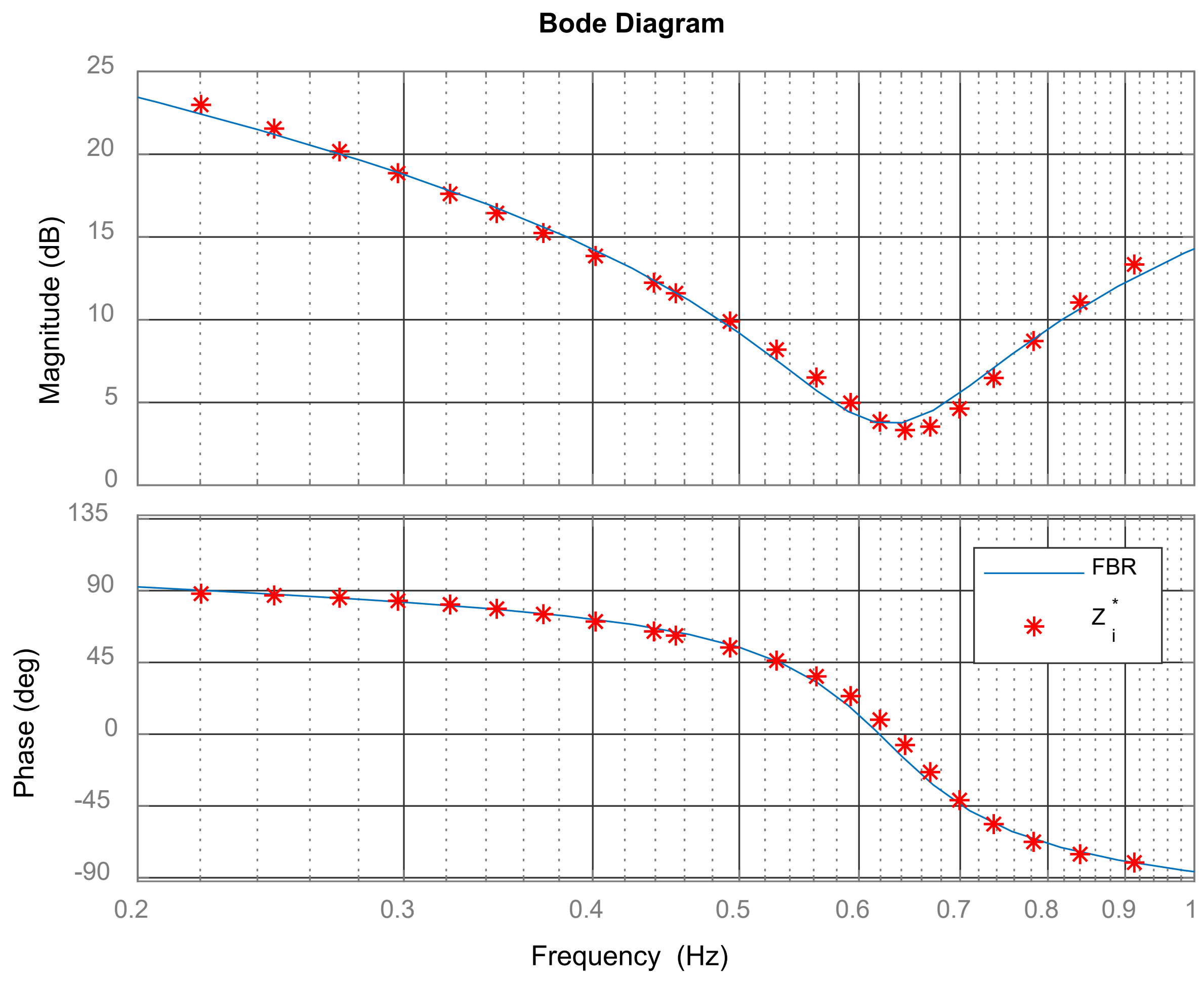

Figure 3: Bode plot of the optimal feedback and its causal approximation

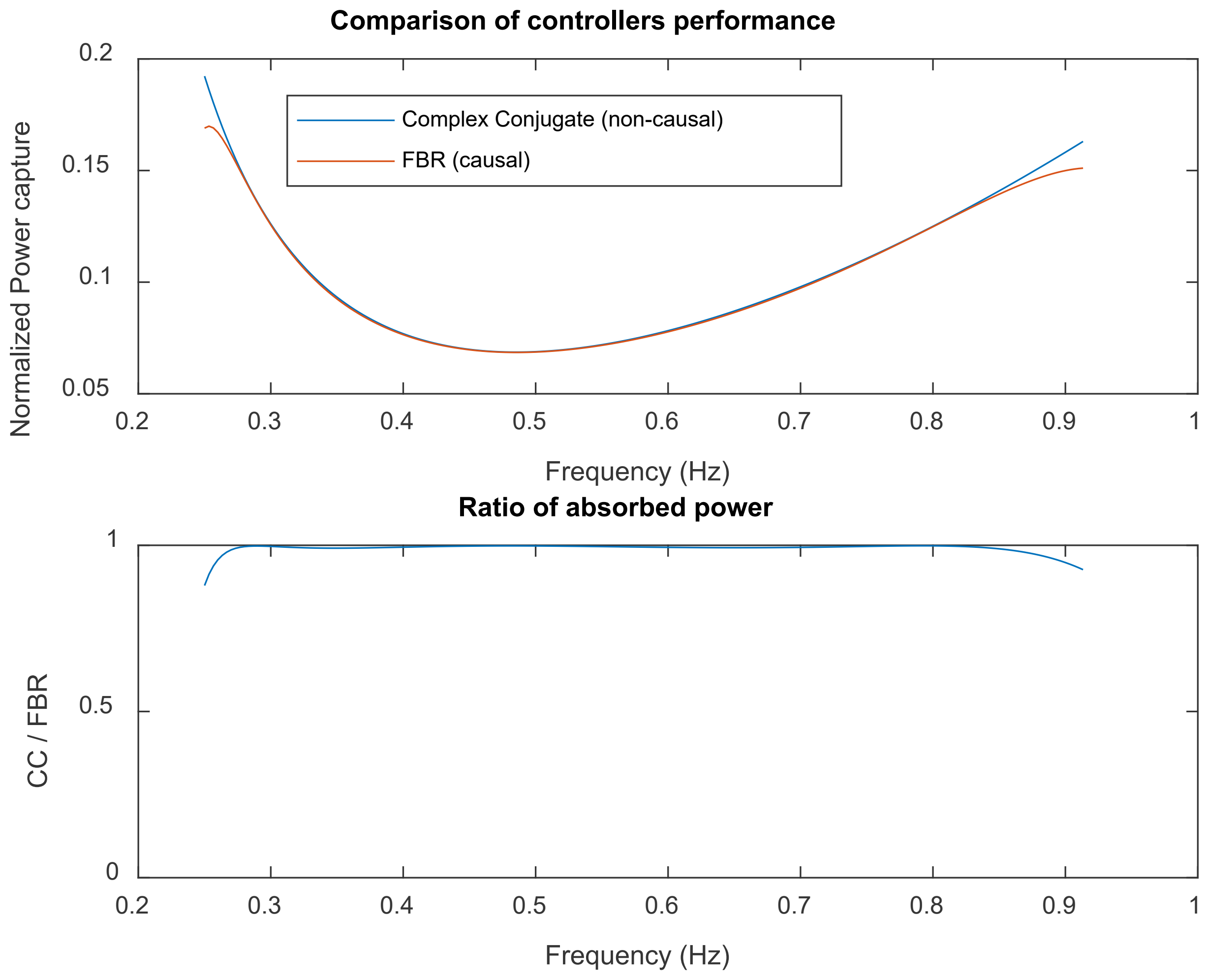

Figure 4: Comparison of the Power Absorbed by the CC control and the FBR Control

References

1. Falnes, J. Ocean Waves and Oscillating Systems Cambridge University Press, 2002.
2. R. G. Coe, G. Bacelli, D. Patterson, D. G. Wilson, Advanced WEC Dynamics & Controls FY16 Testing Report; SAND report :SAND2016-10094; available at: https://mhkdr.openei.org/submissions/151

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