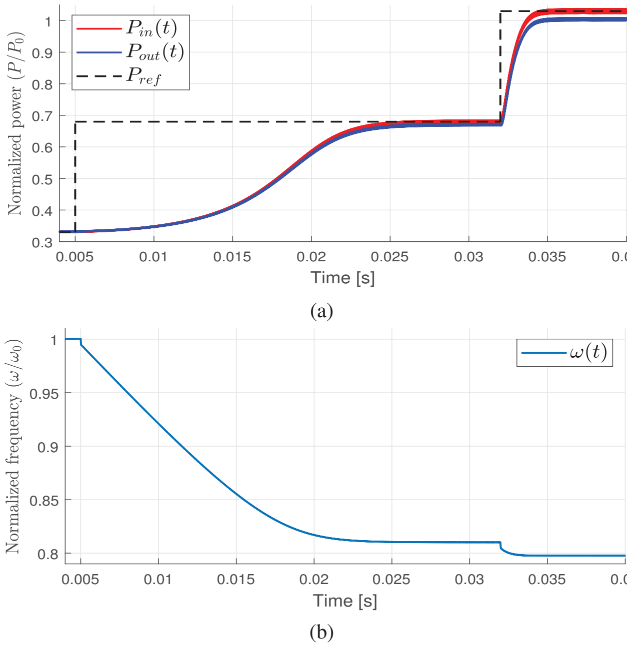

Fig. 15. Response to steps in the power reference with control based only on sending side feedback.

output power. As indicated by the figure, the power reference is increased slightly above 1.0 to compensate for the losses in the system. The operating frequency resulting as output from the PI-controller in Fig. 13 is shown in Fig. 14c. As can be seen, the response is much faster in the case of high coupling coefficient, which is expected when considering the frequency trajectory in Fig. 5 and the frequency characteristics in Fig. 12. The results also confirm how the operating frequency resulting from the closed-loop controller corresponds to the trajectory for maintaining nominal power according to 5.

Another example of the closed-loop power control performance is shown in Fig. 15. In this case, the system is initially operating at the secondary side resonance frequency according to the red curve in Fig. 4a with $k = 3k_{knom}$ and a correspondingly low power reference of 0.32 pu. A step in the sending side power reference to 0.66 pu is applied at t = 5 ms, and a second step in the power reference is applied at t = 32 ms, bringing the system to the operating point corresponding to nominal power transfer indicated by the red circle in Fig. 4a. The operating frequency resulting from the PI-controller is shown in Fig. 15b. The results clearly illustrate how the response is stable and well damped over the entire operating region, although much faster when approaching operation at rated power at high coupling.

V. Conclusion

This paper has presented a time-invariant state-space model of a Series-Series (SS) compensated Inductive Power Transfer (IPT) system designed for battery charging with minimized component ratings. The evaluated system is intended for power flow control by off-resonant operation during variations in the coupling conditions, which is obtained by utilizing the bifurcated characteristics of the IPT system to allow for frequency control with constant input and output voltages. The presented model accurately represents the influence of the Constant Voltage Load (CVL) characteristics resulting from a receiving side diode rectifier directly interfaced to the battery. The linearized state-space model is utilized to evaluate the small-signal dynamics over the full range of expected operating conditions. This small-signal analysis is also utilized to design a simple but robust PI-controller, which can operate with only sending side feedback for regulating the power flow in response to variations in the coupling conditions.

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