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The modelling of a squirrel-cage induction generator in an oscillating-water-column wave-energy converter

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Abstract

The research is focused on the modelling of a squirrel-cage induction generator in dynamic generation involving ocean-wave energy. The chosen application includes an oscillating water column fitted with a Wells turbine.

The modelling approach is based on the evaluation of existing generator models. These include the equivalent steady-state and dynamic models which are considered from a time-domain (differential equation) perspective. Since generation is dynamic in nature, model stability is an important component of model evaluation.

The evaluated models provide information regarding the electrical and mechanical operational variables of the generator. Power flow and energy loss between the mechanical and electrical subsystems are easily calculated from these variables.

The wave-energy converter excluding the induction generator is not explicitly considered. The generator models are evaluated by considering typical generator inputs which are representative of the given application. These dynamics are reproduced experimentally and in simulations with a comparison of generator response allowing for a conclusion on model performance. Generator inputs include the stator voltage excitation and turbine torque with the generator response given by the stator currents and rotor velocity. Electrical and mechanical power are also considered.

Dynamic generation is broken down into two modes of operation: the first mode involves generation for a constant sea state and the second mode involves generator operation for a change in sea state. The dynamics for the first mode involve a set generator speed (set voltage supply) and a sinusoidal prime-mover torque. Dynamics for the second operating mode are not well-defined owing to system variations. Since only the generator model is considered, an informative dynamic is tested providing an indication of possible model performance. The tested dynamic involves a sinusoidally-varying stator frequency and prime-mover torque.

The steady-state model considered from a time-domain perspective is found to be unstable for all generating slip values and is, therefore, unsuitable for the given generation application.

The dynamic model shows good agreement between experimental and simulated generator response for the two operating modes identified. In conclusion, the model is applicable for a constant sea state with a wave period of up to $0.2\,\mathrm{s}$. Furthermore, it is suspected that the dynamic model is applicable in the case of a change in sea state. Cases involving magnetic saturation and parameter variation are left for future development.

The dynamic-model evaluation assumes a balanced stator-voltage excitation – strange electrical transients including electrical faults are not considered.

An important simulation consideration involves the quantification of state-variable initial conditions. Initial rotor currents are problematic as these are not easily measured or defined in a practical squirrel-cage rotor construction. The initial rotor currents are approximated by a phasor analysis of the steady-state circuit model at zero time.

The use of an inverter-based generator excitation for the experimental work poses an analysis problem owing to the pulse-width-modulation-based voltage supply (not truly sinusoidal). This is solved by considering only the fundamental component of the stator voltage and current. Second-order low-pass filters are used to facilitate such measurements.