Study of Gear Ratio in Tidal Current Power Generation System

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ABSTRACT

Tidal current generation has advantages over other types of renewable energy sources for operation when connected to a power grid, and the capacity of tidal current generation to produce power can be predicted using the periodicity of the tidal current. In this paper, we propose a method for selecting gear ratio and generator capacity, which are fundamental design specifications for a tidal current generation system configured with a Darrieus-type water turbine and squirrel-cage induction generator coupled with a step-up gear. The proposed method is applied to a tidal current generation system constructed from the largest-sized turbine that we have developed and studied. This paper shows the gear ratio and generator capacity that maximize generated energy to demonstrate the effectiveness of the proposed method.

KEY WORDS: tidal current generation; Darrieus-type water turbine; gear ratio; smoothing spline; occurrence probability of current speed

INTRODUCTION

Because of increasing awareness of environmental issues, use of renewable energy sources such as solar power, wind power, and ocean energy is attracting attention as a way to help curb global warming. One type of ocean energy is found in the flow of water in tidal currents, which periodically reverse direction. Herein, tidal current power generation refers to a system in which a Darrieus-type water turbine, placed into the current flow, converts the current flow energy into rotational energy, which is then converted into electrical energy by a generator connected to the water turbine. We have previously studied the properties and power generating characteristics of the Darrieus water turbine when placed in a natural flow such as a tidal current by conducting waterway and ocean experiments (Kihoh S, Suzuki K and Shiono M, 1993), (Shiono M, Suzuki K and Kihoh S, 1999).

The flow rate of a tidal current is periodic, changing with a nearly sinusoidal shape over time, with the direction of flow reversing every half-cycle. The duration of the period may be either a half-day or a full-day, depending on the location (Kondo H, Uehara H, Kihoh S, Miyazaki T and Yano K, 1996). Thus, because tidal currents are periodic, an electric power is predictable, unaffected by weather, which is a significant advantage over solar and wind power generation for operations connected to a power grid.

Tidal current power generation, because its input fluctuates, is similar to wind power generation, and therefore power generating methods similar to those for wind power generation can be considered. Specifically, there is a constant-speed operation method in which the rotational speed exhibits almost no fluctuation in response to a fluctuating input, and a variable-speed operation method for controlling the rotational speed to improve efficiency (Kai T, 2004), (Ushiyama I, 2000), (Yamada T and Inomata N, 2000). A squirrel-cage induction generator is used with the constant-speed operation method, and a wound rotor induction generator and synchronous generator are used with the variable-speed operation method. A system that uses a synchronous generator cannot be connected directly to a power grid and is therefore connected via a converter and an inverter. Despite the many advantages, such as higher efficiency resulting from wind turbine pitch control and inverter control, and a relatively small amount of output fluctuation, such a variable-speed system is typically complex and expensive.

In contrast to ocean currents, tidal currents are weak in the open sea and are stronger near the shore. Additionally, the current speed, which varies from sea level to the sea floor, is higher in the upper-levels close the water surface (Kondo H, Uehara H, Kihoh S, Miyazaki T and Yano K, 1996). Because the energy per unit time is proportional to the cube of speed. Consequently, it is advantageous to install tidal current power generation systems in the upper level. However, in this case, the water turbine used as a generator must be sufficiently small that it does not impede boat navigation or commercial fishing, resulting in smaller expected power generating capacities than wind power generators. For such small capacities, variable-speed operation using an inverter or other converter is costly. Thus, as a generation method for a tidal current power generation system connected to a power grid, constant-speed operation using a squirrel-cage induction generator is simplest and most advantageous in terms of cost and maintainability.

For a tidal current power generation system in which a Darrieus water turbine and a squirrel-cage induction generator are connected with a step-up gear, the present study proposes a method for selecting the gear ratio and the rated capacity of the induction generator to maximize the generated energy. Using current speed estimates for the Akashi Strait covering a 1-year period (2003), the proposed method is applied to a tidal current power generation system using a water turbine that the authors have previously built as a prototype and studied (Kihoh S,