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Planning for tidal current turbine technology: A case study of the Gulf of St. Lawrence

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ABSTRACT

The combustion of fossil fuels for purposes of energy production has accelerated the rate at which the planet is warming, thereby causing adverse effects on natural ecosystems across the globe. The consequences of climate change arising from the use of conventional fuels such as coal, oil, and gas demands a shift towards the use of sustainable, emissions-free renewable energy technologies. When planning for the implementation of new energy systems, several factors must be examined in order to determine the viability of a system to meet energy demands in a sustainable and efficient manner. This paper provides an overview of tidal current turbines (TCTs), examining how they function to produce electricity, the possible environmental impacts surrounding large-scale implementation, associated economic factors, and public acceptability. A case study of the Gulf of St. Lawrence is presented as an implementation site, demonstrating the potential for TCTs to assist in phasing out the use of fossil fuels for electricity generation on the Newfoundland island interconnected electricity system. A multi-criteria decision making matrix is presented to discern the benefits of TCTs compared to fossil fuels for the purpose of electricity generation. The paper concludes by examining the potential future of TCTs in the world.

1. Introduction

Current global energy demand is supplied primarily by environmentally detrimental fuel sources such as petroleum, natural gas, and coal, and non-renewable nuclear energy, collectively accounting for 87% of world's energy production, while renewable energy sources such as solar, wind, geothermal, and biomass only account for 13% [51]. However, as global atmospheric temperatures rise due to the greenhouse effect perpetuated by the excessive burning of fossil fuels, an increase in focus of policy makers has been placed on the development and implementation of clean renewable energy technologies to meet the energy demands of communities across the globe in a sustainable, emissions free manner [37].

The progressive implementation of plans, policies, and programs throughout the past two decades that support the deployment of renewable energy systems can be seen through a vast spectrum of scale including international treaties such as the Kyoto Protocol [39], national adoption targets such as the UK's National Renewable Energy Action Plan, provincial incentives such as the Ontario Feed in Tariff (FIT) Program, and regional and municipal declarations to become 100% renewable as is the case for Oxford County, Ontario, and Vancouver, British Columbia respectively.

According to Kleinpeter [25], there are six primary renewable energy sources which technologies can draw upon: solar, wind, biomass, geothermal, hydropower, and ocean energy. While technologies such as solar photovoltaic (PV) and onshore wind turbines have been thoroughly researched, tested, implemented, and analyzed due to the maturity of their technological development, the assessment of technologies deriving energy from the ocean such as tidal current turbines (TCTs) has been relatively neglected. In theory, harnessing less than 0.1% of the possible power of the oceans waves, thermal capacity, and tidal ranges and currents has the capability to meet the worlds energy demands five times over [5]. However, due to the infancy status of ocean power technologies, large-scale implementation has yet to be realized.

When planning for an energy system, planners must take into account several dynamic factors surrounding the implementation a particular technology. This paper will provide an overview of tidal current turbine technology; how it operates to produce electricity, an examination of the site specific conditions required to optimize energy output; and a review of its current implementation status. The paper will then provide an assessment of perceived environmental impacts, economic factors surrounding its implementation, and public acceptability of the technology. A case study of the Gulf of St. Lawrence will be presented as a possible site for implementation of TCT technology to provide electricity for the island of Newfoundland. An assessment of how communities in Newfoundland currently meet their energy needs will be reviewed. Drawing upon a literature review, a multi-criteria decision making matrix will then be formulated, presented, and analyzed in order to discern the benefits of implementing TCTs in the Gulf of St. Lawrence over the use of fossil fuels to provide electricity to the island of Newfoundland. Finally, the results of the matrix will be

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assessed and a discussion of the future potential of TCT technology will be theorized.

2. Overview of TCT technology

2.1. Production of electricity

TCTs are an attractive source of renewable energy due to the predictable conditions under which they function to produce electricity. TCT structures, very similar to the functional design parameters of wind turbines [35], consist of a configuration of typically three blades, either mounted on a horizontal or vertical axis to a hub (together called a rotor), and connected to a gearbox, which is connected to a generator. The technology is placed on the ocean floor through various different engineering options (which will be discussed later), and extracts kinetic energy dissipated by tidal movements to turn the blades, rotate the rotor, and turn the generator via a gearbox, converting the speed of the rotor shaft to the anticipated output speed of the generator shaft.

Tidal current movements result from the gravitational and centrifugal forces perpetuated by the relationship of physics between the earth, sun, and moon [8]. This gravitational and centrifugal process produces tidal flows both towards the coast, known as the flood current, and receding from the coast, known as the ebb current. This process occurs exactly every 24 h, 50 min, and 28 s. Since many TCT designs have been engineered to operate in both flow and ebb tide directions via a pitch and yaw system that orients the rotors to face perpendicular to the direction of the incoming tidal current flow, as is the case with the Atlantis AR1500 and AHH HS1000 TCT models scheduled for commercial deployment in the Pentland Firth in northern Scotland as a part of the MeyGen project this year 2016 (Atlantis Resources Ltd. [2]), the technology can operate to produce electricity under exact predictable conditions, making them advantageous with regards to the consistency of projected energy generation in comparison to other renewable energy technologies such as wind and solar, whose predictability is hindered by inconsistent weather patterns [38]. The electrical energy produced by the turbines can then be transmitted to consumers by either connecting individual TCT transformers to an onshore transformer station, preferable for near-shore arrays, or by connecting individual TCT transformers to an offshore transformer station, preferable for far-shore arrays, which would then transmit electricity through a single cable to an onshore station to manipulate the output voltage to grid accommodation specifications (Myers and Bahaj [30]).

2.2. Optimal conditions for application

2.2.1. Environmental conditions

An in depth literature review of site conditions for the optimal application of TCTs reveal that locations able to support the implementation of the technology are fairly site-specific, and therefore relatively limited in comparison to other renewable energy technologies such as wind, solar, and biomass [13]. Fraenkel [15], amongst many others, suggest that, in order to be economically and structurally feasible, TCTs must be located in areas where mean spring peak tidal currents are faster than 4–5 knots, or 2–2.5 m/s (meters per seconds). These optimal locations for harnessing tidal power can be found at sites where narrow straights are exhibited between substantial landmasses or are adjacent to headlands such as capes and peninsulas [37].

While site specific, Hammons [18] estimates that harnessing the total global potential of tidal energy from costal areas can produce 500–1000 TW h/yr (terawatt hours per year) of electricity. In Canada alone, Triton Consultants Ltd., in cooperation with the Canadian Hydraulic Centre and Natural Resources Canada, undertook a preliminary tidal resource inventory based on Canadian Sailing Directions, Nautical Charts and Tide Books, Tide and tidal current constituent data, and Numerical Tidal modeling data, and identified 191 potential sites for the extraction of tidal current energy, averaging 221 MW (megawatts) of electricity generation per site, and collectively producing and estimated 42,240 MW [44]. However, it is noteworthy to consider that these figures of the full potential for the utilization of tidal current energy does not reflect dynamics concerning environmental impacts, technological development, climatic and ecological factors (climate change and vast ice sheets), power grid accessibility, hydrogen economy developments, the effect of energy extraction on existing flow conditions, and economic factors.

2.2.2. Technological layout optimization

The optimal layout of a TCT farm must take into account geometric measures that may potentially manipulate the wakes (an area of flow immediately behind an object, caused by the flow of surrounding fluid on either side of the object) produced by TCTs to increase energy production, as well as avoid structural damage to technologies via placement of a TCT too close to the downstream wakes resulting from TCTs upstream [29].

In an engineering research and development (R & D) study conducted to determine the optimum layout configuration of an array of TCTS, Myers and Bahaj [31] constructed, tested, and analyzed a downscaled model of tidal current turbines (using specially designed discs to represent turbines) at the University of Southampton, England. Their research sought to maximize the energy production efficiency of TCTs while simultaneously upholding the structural inte201b201grity of the technology. The results demonstrate an optimal layout configuration of 1.5D (D = disc diameters) of lateral separation between two turbines in a front row, which enhances their combined wakes to provide and additional power of 22% to a third turbine placed directly between the wakes 3D downstream, as seen in Fig. 1.

However, the article does not explore the effects of a wake of one TCT on the two laterally spaced TCTs in order to account for daily changes in tidal flows from flood tides to ebb tides. This means that, if placed in a grouping of four, in order to achieve this additional 22% increase in power output of a single TCT located downstream of the wakes of two TCTs throughout the entire tidal movement cycle, another

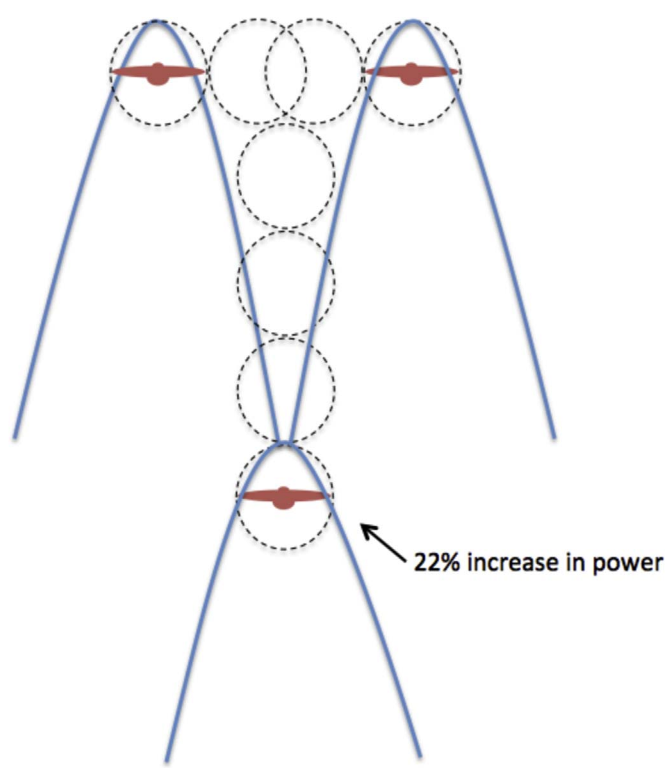

Fig. 1. Concept drawing based on Meyers & Bahaj's layout optimization study.