Tidal Power & Tidal power Generator: A Stochastic Source of Renewable Energy

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Abstract:

Tidal energy, also known as tidal power, generates electricity from hydropower which converts the energy of tides into electricity or other useful forms of power. Till date, use of Tidal power has not started rapidly for generation of electricity, but it has a huge potential. Compare to wind energy and solar power Tides are more predictable. The few limitations compare to other sources of renewable energy are as follows: tidal power has traditionally suffered from relatively high cost and limited availability of sites with sufficiently high tidal ranges or flow velocities, thus constricting its total availability. However, recent technological developments and improvements have taken place both in design (e.g. dynamic tidal power, tidal lagoons) and turbine technology (e.g. new axial turbines, cross flow turbines), indicate that the total availability of tidal power may be much higher than previously assumed, and that economic and environmental costs may be brought down to competitive levels. Due to gravitational interaction with the Moon and Sun and the Earth's rotation, the Earth's tides are produced and so tidal power is practically inexhaustible and known as a renewable energy resource. This phenomenon is used to generate electricity with a help of tidal generator. This paper describes various processes to generate electricity from Tidal power. More over it also describes the principle and constructional feature of Tidal Power generator.

Keywords: B2B Converter, Doubly Fed Induction Generator, Renewable Energy, Tidal Power Generator

1. Introduction :

Fossil fuel resources such as oil, gas and coal are highly on demand in today's worldwide energy production. The concern is these resources are limited and their uses emit a lot of green house gasses in environment. According to the Kyoto protocol, there is an agreement to reduce the emission of greenhouse gases. To provide a sustainable power production in the future and respecting the Kyoto protocol at the same time, there is a growing demand for energy from renewable sources such as wind, geothermal, solar and ocean.[1]

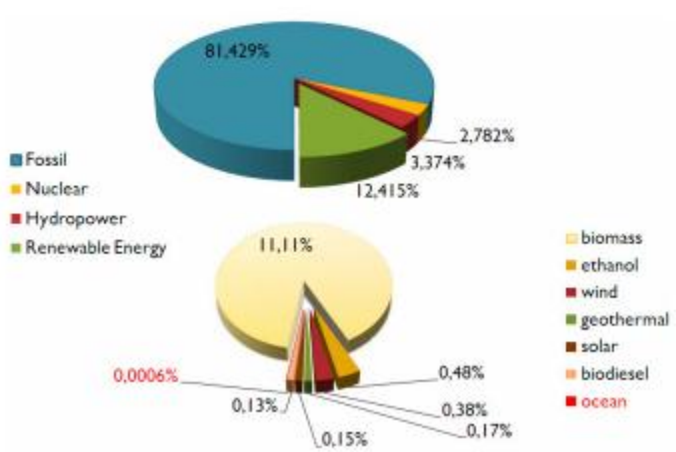

Fig 1: Renewable Energy Share of Global final Energy Consumption, 2009 [4]

Renewable energy is generally defined as energy that comes from resources which are naturally replenished on a human timescale, such as sun light, wind, tides, waves and geothermal heat. According to REN21's 2014 report renewable energy contributed 19 percent to our global energy consumption and 22 percent to our electricity generation in 2012 and 2013, respectively, and worldwide investments in renewable technologies amounted to more than US$214 billion in 2013.[2]

Besides Solar and wind power , a vast source of renewable energy is tidal power as ocean covers 70% of the earth. The energy is stored in oceans partly as thermal energy, partly as kinetic energy (waves and currents) and also in chemical and biological products. Ocean is a source of various renewable energy as categorized by various techniques for extraction energy from the sea. They are: wave energy, marine and tidal current energy, ocean thermal energy, energy from salinity gradients (osmosis), and cultivation of marine biomass. The kinetic energy of marine and tidal currents can be converted to electrical energy by using relatively conventional turbine technology. To harness the kinetic energy in waves present a different set of technical challenges and a wide variety of designs have been suggested. Ocean thermal energy conversion is possible in locations with large temperature differences, extracting energy with a heat engine

Sites with attractive wave climate and intense tidal currents are abundant in the vicinity of the European coastline. It has been shown that 48% of the European tidal resource is in the UK, 42% in France, and 8% in Ireland For a remote coastal or island area, only a stand-alone tidal or wind system cannot provide a continuous supply of energy due to random variations of tidal current and wind speed in different periods and seasons. In order to satisfy the continuous load demand in remote locations, a hybrid energy system with mixed tidal power, wind power and battery storage is an essential option.[5]

There are basically two ways of generating electricity from marine and tidal currents.Several techniques of exploiting and extracting ocean energy have been suggested. The most studied ones are classified as follows: wave energy, tidal current energy, ocean thermal energy, energy from salinity gradients, cultivation of the marine biomass. According to the data provided by UNESCO (United Nations Educational, Scientific and Cultural Organization) in 1981, the total of the theoretical ocean energy capacity is about 76 GW. The potential for the first 4 kinds of the ocean energy is shown in table 1.

TABLE I
OCEAN ENERGY CAPACITY

	Ocean energy capacity
Ocean Thermal Energy	40GW
Energy from Salinity Gradients	30GW
Wave Energy	3GW
Tidal Current Energy	3GW
Total	76GW

For Europe "The Exploitation of Tidal Marine Currents" project sponsored by the EC (European Commission) analyzed 106 locations in European territorial waters, with certain predefined characteristics, to make them suitable for energy exploitation. The aggregate capacity of this selection of sites amounted to an installed rated capacity of (Marine Current Turbines) MCTs of over 12000MW, able of yielding 48 TWh of electrical energy per annum.[1]

2. TIDAL STREAM GENERATOR

A machine that extracts energy from moving masses of water, or tides is a Tidal Steam Generator. . These machines function very much like underwater wind turbines, and are sometimes referred to as tidal turbines. Tidal stream generators are the cheapest and the least ecologically damaging among the three main forms of tidal power generation.

Fig. 2: The world's first commercial-scale and grid-connected tidal stream generator.

As the Earth's tides are ultimately due to gravitational interaction with the Moon and Sun and the Earth's rotation, tidal power is practically inexhaustible and classified as a renewable energy resource. A tidal generator uses this phenomenon to generate electricity. Greater tidal variation or tidal current velocities can dramatically increase the potential for tidal electricity generation.

2.1 Types of tidal stream generators

Since tidal stream generators are an immature technology, no standard technology has yet emerged as the clear winner, but large varieties of designs are being experimented with, some very close to large scale deployment. Several prototypes have been shared with many companies, some of which are yet to be independently verified, but they have not operated commercially for extended periods to establish performances and rates of return on investments.

2.2 Energy calculations

Various turbine designs have varying efficiencies and as a result varying power output. If the efficiency of the turbine "Ĭ" is known the equation below can be used to determine the power output of a turbine.

The energy available from these kinetic systems can be expressed as: $\mathbf{P = \sigma\rho AV^3 / 2}$

Where:: Ĭ = the turbine efficiency

P = the power generated (in watts)

ŏ = the density of the water (seawater is 1025 kg/m^3)

A = the sweep area of the turbine (in m^2)

V = the velocity of the flow Relative to an open turbine in free stream, depending on the geometry of the shroud shrouded turbines are capable of as much as 3 to 4 times the power of the same turbine rotor in open flow.

2.3 Resource assessment

While initial assessments of the available energy in a channel have focus on calculations using the kinetic energy flux model, the limitations of tidal power generation are significantly more complicated. For example, the maximum physical possible energy extraction from a strait connecting two large basins is given to within 10% by**:** $\mathbf{P = 0.22pg\Delta H_{max}\, Q_{max}}$

Where ǒ = the density of the water (seawater is 1025 kg/m³),

g = gravitational acceleration (9.81 m/s2),

ΔHmax = maximum differential water surface elevation across the channel,

Qmax= maximum volumetric flow rate though the channel.

3. Additional advantages of tidal current power generation:

Vertical and horizontal-axis tidal current energy generators are fueled by the renewable and free forces of the tides, and are also free from pollution or greenhouse gas emissions. As an improvement on ocean dam models, however, the new models offer many additional advantages: -

- Because the tidal current models do not require the construction of a dam, they are considered much less costly.
- Because the tidal current models do not require the construction of a dam, they are considered much more environmentally-friendly.
- Because the tidal current models are also cost effective as they do passage of water and offer a transportation corridor (bridge), essentially providing two infrastructure services at the price of one.
- A 'tidal fence' is capable of generating electricity that is comparable to the largest existing fossil fuel based, hydroelectric and nuclear energy generation facilities. Vertical-axis tidal generators can be joined together in series to create the same.
- Being an intermittent and stochastic source of Renewable energy, Tidal current is predictable with exceptional accuracy many years in advance. According to the requirement, power supply along with tidal energy will be more proficient and scheduled. Thus, comparing to wind, solar and wave energy, tidal current has become a much more reliable energy source.
- Present tidal current, or tidal stream technologies are capable of exploiting and generating renewable energy in many marine environments that exist worldwide. Canada and the US, by virtue of the very significant tidal current regimes on its Atlantic and Pacific coastlines – proximal to existing, significant electro-transportation infrastructure - is blessed with exceptional opportunities to generate large-scale, renewable energy for domestic use and export. not require the construction of a dam, further cost-reductions are realized from not having to dredge a catchment area.
- Tidal current generators can produce electricity while tides are ebbing (going out) and surging (coming in), and are also considered more efficient whereas barrage style structures only generate electricity while the tide is ebbing.
- Vertical-axis tidal generators may be stacked and joined together in series to span.

4. Tidal power generator:

Tidal power generators extract energy from the ocean movement due to the tidal phenomenon. This phenomenon is due to the changing gravitational pull of the sun and moon in respect to the earth's oceans. It causes large bodies of water to move towards and away from the shore. These fluctuations are site specific and each location will experience diurnal tides (one high, one low in a tidal day), semi-diurnal tides (two high, two low in a tidal day) or a mixture of the two.[3] Tidal current generation (TCG) converting the kinetic energy of tidal flows into electricity is regarded as a kind of friendly electric power source, which is reliable, low-carbon, highly predictable and with huge potential. Tidal power or tidal energy is a form of hydropower that converts the energy of tides into useful forms of power and electricity. Tidal energy will play an essential role in future electricity generation because of its potential amount, pollution-free, and better predictability of tides than wind and solar power .[4]

Different variable speed technologies can be used in a TPGS .Two popular technologies are:

1) a fully controllable BTB (Back to Back) converter in a DFIG (Doubly Fed Induction Generator) configuration and
2) a full converter configuration with a permanent magnet induction or synchronous generator.

In a DFIG configuration, the power electronic converter needs to handle only a fraction of the total power, which leads to a much lower cost compared to a full converter configuration with a permanent magnet generator.

Structure of a Tidal Power Generator With a DFIG:

A tidal power generator consists of the following main components: blade, gearbox, DFIG, BTB converter, and control system, as shown in Fig. 2

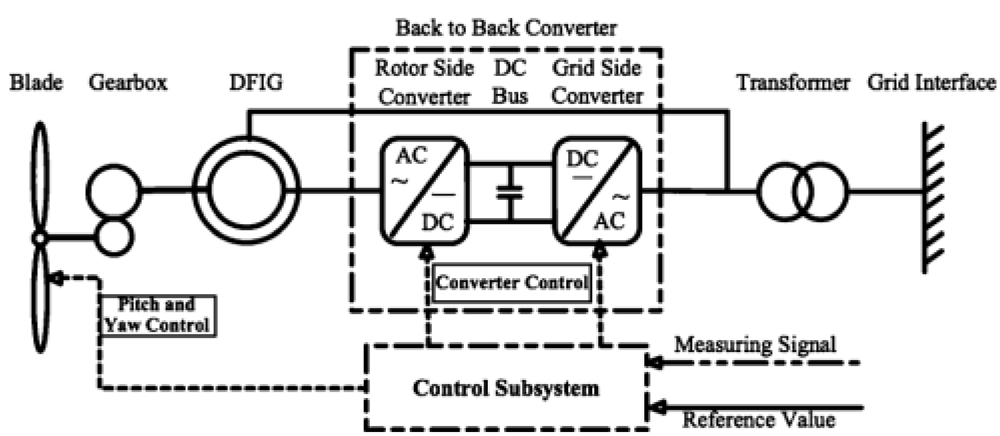

Fig 3: Topology of a Tidal Power Generator with DFIG.

The stator windings of the DFIG are directly connected to a constant-frequency power grid through a transformer, whereas the rotor windings are connected to the grid through a bidirectional power converter and the transformer. The BTB converter consists of two power converters: the rotor side converter (RSC) and the grid side converter (GSC), which are controlled independently from each other. Between the two converters, a DC-link capacitor is placed to maintain the DC-link voltage. The converters normally use IGBTs as switches.

Operation Modes of a DFIG:

A DFIG can operate in idle, sub synchronous or super-synchronous modes. The operation mode of a DFIG depends on rotor speeds and thus on tidal current speeds. The rotor speed can be divided into four speed regions. The relationship between rotor speed and tidal current speed is shown in Fig. 4.

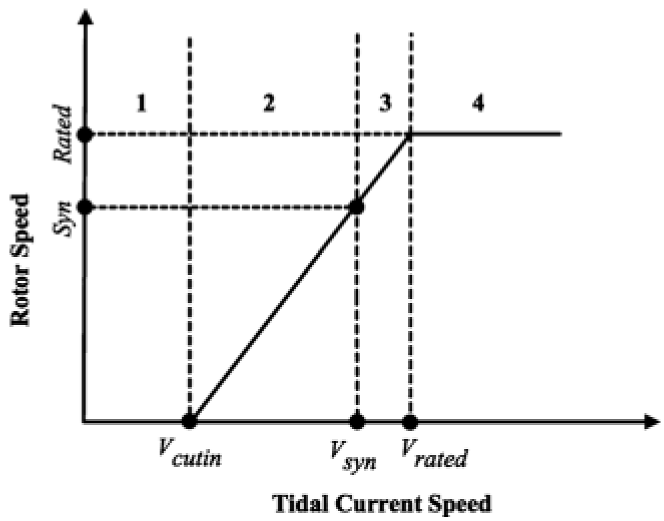

Fig 4: Characteristic between Tidal Current Speed and Rotor Speed

The V_{cutin} , V_{syn} and $_{Vrated}$ denote the cut-in, synchronous, and rated speed of a DFIG in terms of tidal current speed, respectively. Rated and Syn in the -axis denote the rated and synchronous speed in terms of rotor speed, respectively.

In region 1, the tidal current speed is lower than the cut-in speed of the DFIG. The rotor will not turn in this region. The DFIG starts to run when the tidal current speed exceeds the cut-in speed. As the tidal current speed increases, the rotor speed also increases until the rated speed (regions 2 and 3) is reached. When the tidal current speed reaches or exceeds the rated speed, the rotor speed is maintained at the rated speed and the output power of the DFIG is kept at the rated power (region 4). In region 4, the mechanical power can be limited either by pitch or torque control. Region 1 is the idle mode. In region 2, the rotor speed is below the synchronous speed with a positive slip and it is called the sub synchronous mode. The DFIG operates in a super-synchronous mode in regions 3 and 4 with a negative slip. The absolute value of the slip increases as the tidal current speed increases in region 3, and remains constant in region 4. [6]

The topology of the BTB converter is shown in Fig. 5. The RSC works at variable frequencies and variable voltages depending on the rotor's speed, which is dependent on tidal current speed, whereas the GSC works at a constant voltage and a constant frequency since it is directly connected to the power grid through a transformer. The BTB converter is a bidirectional converter, which means that both the RSC and the GSC can work as a rectifier or an inverter. The power loss is different when the converter (RSC or GSC) works as a rectifier or an inverter. The working state of a converter is determined by the operation mode of the DFIG. The GSC works as a rectifier when the DFIG operates in a sub-synchronous mode, while the RSC works as an inverter. On the contrary, the GSC works as an inverter and the RSC works as a rectifier when the DFIG operates in a super-synchronous mode.

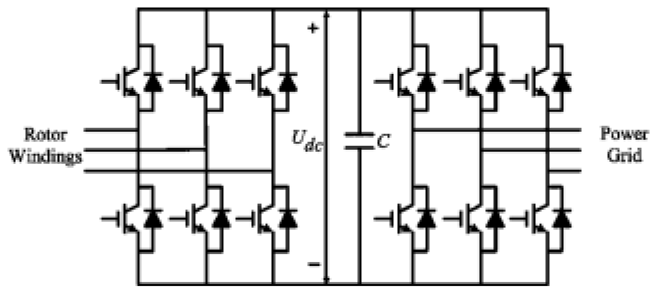

Fig 5: Topology of a B2B Converter

Rotor Power of a DFIG

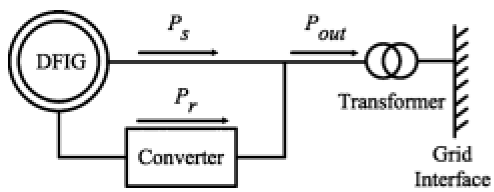

Fig 6: Power flows of a DFIG

The power flowing through a power electronic component must be calculated before its junction temperature can be estimated. The power loss causing temperature rise depends on the electric current flowing through the component while the current is determined by the rotor power and voltage. The power flowing through the BTB converter is the rotor power. In the rotor circuit, active power flows either to or from the rotor, thereby either absorbing or injecting active power to the grid. The power flow of the DFIG is shown in Fig. 6. The positive direction is defined as the power flowing from the rotor to the grid. The output power of the DFIG to the grid is the sum of both stator and rotor power. The relationship between the stator power , rotor power and output power can be expressed as

$$P_r = -sP_s = -\frac{s}{1-s}P_{\text{out}}$$

Where s is the generator slip and can be calculated by

$$s = \frac{n_s - n_r}{n_s} = \frac{V_{\text{syn}} - V_t}{V_{\text{syn}}}$$

Where n_s is the synchronous rotor speed, n_r is the rotor speed, V_{syn} is the tidal current speed corresponding to the synchronous rotor speed, and V_t is the tidal current speed. It can be seen that $s < 0$, when the DFIG operates in the super-synchronous mode and $s > 0$, when the DFIG operates in the sub synchronous mode. As the tidal current speed increases, the rotor speeds also increases and at some point, the rotor speed could be beyond the synchronous speed resulting in a negative slip, which corresponds to a positive rotor power and the super-synchronous operation mode. When the tidal current speed decreases below the synchronous speed, the rotor speed also decreases, and the DFIG operates in the sub-synchronous mode with a positive slip and negative rotor power.

Rotor Voltage

As mentioned earlier, the RSC works at variable voltages and variable frequency whereas the GSC works at a constant voltage (frequency) which is the grid voltage (frequency). The voltage relationship between the stator voltage and rotor voltage can be approximately expressed by

$$U_{rl} = s \times VTR_{SR} \times U_{sl}$$

Where VTR_{SR} is the voltage transformation ratio between the stator and rotor of the DFIG, U_{rl} and U_{sl} are both given in line-to-line voltages. The rotor voltage is used to calculate the current flowing through the RSC and the power loss of the RSC.

Conclusion

A survey of the available literature indicates that the existing methods for calculating tidal power are based on deterministic techniques.This paper presents a detailed study of one of the used Tidal power generating system. It presents a reliability evaluation method for a TPGS with a DFIG. The core of the method is the modeling of the tidal current speed related failure rates of a RSC and GSC. The DFIG has three operation modes: idle, sub synchronous, and super-synchronous modes. In the sub- and super-synchronous modes, the rotor current varies with tidal current speed, resulting in different power losses and thus different junction temperatures of power electronic components which in turn, create the varied failure rates of RSC and GSC. The findings may be further validated using observed output power data.

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