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Control, power and electrical components in wave energy conversion systems: A review of the technologies

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ABSTRACT

The purpose of this paper is to introduce the status of wave energy conversion (WEC) technologies from a different perspective. Past studies based on WEC systems are summarized and classified in terms of WEC system components to clearly reveal the performance, efficiency and development of WEC technologies over the last two decades. It has been proved that the individual components of a WEC system, such as types of wave energy converter and generator motion, control methods and power electronic converter, have a close relationship with each other and that no single component can be optimized without considering the others. It can be helpful to divide into descriptive parts to provide a better understanding of the development process for WEC technologies so that studies based on WEC technologies are discussed by regarding types of wave energy converters, generators, control methods, controller applied sides, waves, power electronic converters and validations and publication year in this paper.

Contents

1. Introduction

Energy is a key to economic and social development. Though the world population and national economic growth continue to affect the energy and electricity demands, approximately 80% of the world's energy demand is still supplied by fossil fuels (petroleum, natural gas, and coal). The world energy demand is expected to grow by 70% by 2050 regarding to International Energy Agency scenario suggested in 2014 [1]. It is assumed that global energy demand will increase by nearly one-third from 2013 to 2040 [2]. Energy indicators show that there is still an energy deficit in the world, with almost 1.1 billion people, approximately 15% of the world population, still living without electricity [3].

There is no need to explain how the energy is important and how the use of renewable energy is inevitable. It is obvious that energy is an important necessity for quality of life standards and strategic development for the nations. An alternative energy source is thus always in the scope of the research topics for current and future energy planning. To mitigate the potential crises caused by the limited resources and the potential disputes between countries, many nations have targeted investing in renewable

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Nomenclature

AACDCR	Active AC/DC rectifier
ACDCBR	AC/DC boost rectifier
ACDCHBBC	AC/DC h-bridge boost converter
AFC	Air flow control
AFPIC	Adaptive fuzzy PI control
AGFPIDC	Adaptive grey fuzzy PID control
AHBACDCR	Active half-bridge AC/DC rectifier
AmC	Amplitude control
AWS	Archimedes wave swing
BQE	Bus quantity enhancer
CC	Current control
CycWEC	Cycloidal WEC
DCACI	DC/AC inverter
DCDCBBC	DC-DC buck-boost converter
DCDCBoC	DC-DC boost converter
DCDCBuC	DC-DC buck converter
DCDCC	DC-DC converter
DeC	Declutching control
DTC	Direct torque control
FC	Feedback control
FFC	Feed-forward control
FLC	Fuzzy logic control
FOC	Field-oriented control
HVDC	High voltage direct current
LC	Latching control
LoC	Load control
NNC	Neural network control
OB	Oscillating bodies
OC	Optimal control
OOC	On-off control
OT	Overtopping
OWC	Oscillating water column
PAC	Phase+amplitude control
PACDCR	Passive AC/DC rectifier
PC	Predictive control
PhC	Phase control
PIC	PI control
PID	Proportional+integral+derivative
PIDC	PID control
PLC	Passive loading control
PM	Permanent magnet
PoC	Power control
PPICC	P–PI cascade control
PTO	Power take off
RC	Reactive control
RoC	Robust control
RSC	Rotational speed control
SMC	Sliding mode control
SPF-GP	Switched power filter-green plug
STC	Slow-tuning control
TC	Torque control
UnC	Uncontrolled
UNSD	Unused
VC	Valve control
VoC	Voltage control
WEC	Wave energy conversion
WSE	Wave star energy

energy as an alternative to the conventional sources.

Renewable energy provides a possibility to reduce environmental problems and increase source diversity. Many countries have announced regulations to encourage investors to use renewable energy. Over the last decade, the use of renewable energy sources such as wind and solar has increased tremendously, such that some countries are generating approximately 4–20% of their energy needs from wind and solar resources. Although they are not used as frequently as solar and wind energy, wave and tidal energy have recently become alternatives to conventional sources as devices are developed to resolve the power quality problems. Because one of the main problems in renewable energy applications is the interfacing of the generating units with the user, the interface devices have an important role in renewable energy utilization. In addition to the technical problems, the investors of renewable energy systems are still facing problems with feed-in tariffs, renewable portfolio standards, local regulations, and financial support.

Renewable sources have grown to supply estimated 22.8% of the global electricity in 2015 [4]. At least 145 countries have renewable energy policy targets or support policies [4]. Moreover, total global investment in renewable energy in 2014 has increased by 16.4% over the previous year. As the renewable energy capacity has grown, the costs have decreased accordingly. At least 100 jurisdictions at the national or provincial level have enacted feed-in tariff programs. Many policies have been implemented to popularize renewable energy applications, such as direct capital investment subsidies and grants, tax incentives, credits, and public financing [4–6].

Studies about ocean/wave/tidal energy have been discussed widely in literature with different perspectives. This paper aims to review the studies focused on WEC technologies published for about two decades. Different approaches, methodologies and points of view for the problem solutions are introduced and discussed in these studies. The approaches and methodologies are mostly focused on electrical wave energy converter, generator, control methods, power electronic converter, wave types and power quality issues. A detailed discussion and conclusion of WEC technologies are presented with a different point of view. Thus, WEC related topics such as costs, reliability and efficiency are not discussed in this paper. However, they can be found in literature [7–13].

2. Wave energy

Over 70% of Earth's surface is covered by oceans, which are the world's largest solar collectors. Moreover, the oceans are the biggest untapped energy sources on Earth. The power density of wave energy is much higher than that of wind or solar energy. Depending on the sea surface, weather conditions, the shore structure and the location on Earth, the magnitude and periodic characteristic of waves may vary. Besides, waves show different characteristics from season to season, day to night, day to day, even hour to hour during the same day. Wave energy converters can produce power up to 90% of the time according to design and application methodologies, whereas wind and solar power systems produce 20–30% of the time [14–17].

Literature survey on the studies related to WEC systems is performed and categorized with subsections such as wave condition (regular and irregular waves), wave energy converter type (oscillating bodies, oscillating water column, overtopping), generator type (rotary and linear), control (mechanical and electrical sides), power electronic converter topology, and study type