HYBRID ENERGY SYSTEMS SERIES

Ibrahim Dincer
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HYBRID ENERGY SYSTEMS FOR OFFSHORE APPLICATIONS

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Hybrid Energy Systems for Offshore Applications

HYBRID ENERGY SYSTEMS SERIES

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Hybrid Energy Systems for Offshore Applications

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Preface of the Series Editor

Hybrid energy systems are defined as the integration of several types of energy generation equipment such as electrical energy generators, electrical energy storage systems, and renewable energy sources.[1] They represent a very promising sustainable solution for power generation in standalone applications. Technology will continue to evolve in the future, so that it will have wider applicability and lower costs. There will be more standardized designs, and it will be easier to select a system suited to particular applications. There will be increased communication between components, facilitating control, monitoring, and diagnosis. Finally, there will be increased use of power electric converters. Power electronic devices are already used in many hybrid systems, and as costs go down and reliability improves, they are expected to be used more and more.

This series provides a medium for publishing up-to-date research and explaining the concepts behind the development of hybrid technology systems, including advances in theories, developments, principles, and bridges to practical case studies and applications in the overarching subjects related to advancing the energy mix. The intended audience are researchers, engineers, and managers in energy engineering, petroleum engineering, pipeline engineering, offshore engineering, nuclear engineering, and environmental engineering.

My hope is that this series drives forward the energy transition needed to meet all of the world's energy demands in a sustainable and economically viable way.

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[1] https://www.sciencedirect.com/topics/engineering/hybrid-energy-system (Accessed on January 13, 2021).

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Preface

Due to rapidly increasing worldwide population and growing energy demands, the development of renewable energy technologies has become of primary importance in the effort to reduce greenhouse gas emissions. In addition, rapid increases in oil prices, coupled with concerns about the stability and security of fossil fuels extraction, have led to emphasized interest in the exploitation of offshore renewable energy sources, such as offshore wind, sunlight, waves, and tidal currents. However, it is often technically and economically infeasible to transport discontinuous renewable electricity for long distances to the shore. Another shortcoming of nonprogrammable renewable power is its integration into the onshore electrical network without affecting power quality, grid stability, and the dispatching process.

On the other hand, the offshore oil and gas industry is striving to reduce the overall carbon footprint from onsite power generators and limiting large expenses associated with carrying electrical energy from the shore in the case of remote facilities. Furthermore, the increased complexity and expansion toward challenging areas of offshore hydrocarbon operations call for higher attention to safety and environmental protection issues against potential major accident hazards. The rise of offshore oil and gas assets approaching the end of their useful life requires a careful dealing with complex evaluation of the decommissioning options. Another multidimensional problem is the monetization of offshore natural gas reservoirs, particularly in the case of stranded and depleted gas fields close to the shore.

Innovative hybrid energy systems, as Power to Gas (P2G), Power to Liquid (P2L), and Gas to Power (G2P) options, which appears to be potentially implemented at offshore locations, would offer the opportunity to overcome challenges of both the renewable and the oil and gas sectors by different strategies. The chemical conversion of renewable power into gas and liquid synthetic fuels (P2G and P2L) at offshore oil and gas facilities allows the easing of storage and transportation of renewable energy from remote areas and creating new opportunities for aging offshore structures. On the other hand, gas turbine energy balancing systems, coupled with renewable plants in G2P offshore projects, offer the advantages of improving the dispatchability of renewable power injected into the grid and of valorizing untapped gas resources. Despite the widespread experience of these concepts at the onshore context, no evidence has been found on offshore applications, and the existing literature studies are limited to feasibility assessments of the sole offshore P2G—hydrogen option.

In this book, Chapter 1 introduces the concepts of sustainability and inherent safety and highlights the importance of quantitative metrics for the evaluation of alternative options in the offshore context.

Chapter 2 presents various options for renewable power production from offshore renewable energy sources, including the main challenges related to the offshore renewable industry and opportunities for development through synergy with the offshore oil and gas sector. Chapter 3 contains the details of P2G, P2L, and G2P hybrid energy systems for the exploitation of offshore renewable sources at the given offshore oil and gas sites. Chapter 4 primarily concerns the analysis and modeling of the systems as described in Chapter 3 from the point of view of thermodynamic, economic, environmental impact, and inherent safety assessments. Chapter 5 describes a portfolio of novel methodologies based on multicriteria indicators for the sustainability and safety performance comparison of alternative P2G, P2L, and G2P offshore hybrid energy options. These methods can be used as decision-making tools supporting the choice of innovative hybrid energy systems for offshore green projects in the early design phases. Three case studies are defined in Chapter 6, covering different offshore scenarios of concern under various case studies, to provide an assessment of the effectiveness and value of the suite of tools developed. The outcomes of the case studies show that the supporting tools and novel metrics developed are able to capture criticalities of the analyzed offshore systems and to orient the choice of the best P2G/P2L/G2P hybrid energy option from the sustainability and/or safety perspectives. Lastly, the book closes with Chapter 7, which aims summarizing the conclusions and addressing some recommendations for the further development and validation of systematic methodologies based on sustainability and inherent safety indicators for offshore hybrid energy systems.

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Nomenclature

$A_{\text{oil-sl}}$	surface area of the oil slick (m^2)
$A_{\text{oil-th}}$	surface area of the oil thick slick (m^2)
A_{p}	aperture area of single collector (m^2)
A_{rot}	swept area of rotor of the wind turbine (m^2)
A_{vuln}	vulnerability area of a given target (m^2)
AEP	gross annual energy production (MW h/y)
AHI	inherent hazard index addressing assets target (m^2/y)
API	potential hazard index addressing assets target (m^2)
ASI	aggregated sustainability index
AV	availability
B	annual production of final product (MW h/y)
c	average cost per unit of exergy ($/kW h)
c_{w}	scale factor of Weibull distribution
$\dot{C}$	cost rate ($/h)
C_{bm}	bare-module cost from Guthrie method ($)
C_{GHG}	cost due to GHG emissions (€)
C_{p}	power coefficient of wind turbine
C_{prod}	total production cost ($/y)
C_{tci}	capital investment cost ($)
$C_{\text{imb-}}$	cost due to negative power unbalance (€)
cf	credit factor (1/*y*)
CI	consistency index
CR	consistency ratio
d	damage distance for human target (m)
d_{p}	internal pipe diameter (inch or mm)
D	diameter of rotor of the wind turbine (m)
e	damage distance for assets target (m)
e_{GHG}	greenhouse gas emissions (kg_{CO2eq}/h)
E	efficiency factor for pipeline design
EHI	inherent hazard index addressing environment target (tonnes/y or tonnes d/y or km^2/y or km^2 d/y)
EPI	potential hazard index addressing environment target (tonnes)
ex	specific exergy (kJ/kg)
$exCOP$	exergetic coefficient of performance
$\dot{E}x$	exergy rate (kW)
f	exergoeconomic factor
F	total subindicators in each aspect of sustainability
g	damage parameter for water column target (m)
G_{solar}	solar radiation (W/m^2)
h	specific enthalpy (kJ/kg)
H_{m0}	spectral significant wave height (m)
H_{s}	wave significant height (m)
H_{t}	total number of hours in the considered period
HHI	inherent hazard index addressing the human target (m^2/y)

HHV	higher heating value (kJ/kg)
HPI	potential hazard index addressing the human target (m^2)
I	general indicator
In	incentive (€/MW h)
k_w	shape factor of Weibull distribution
L	characteristic length of wave converter (m)
L_p	pipeline length (miles or km)
LCOP	levelized cost of product (units of currency per MW h)
LCOE	levelized cost of product (units of currency per MW h)
LGHG	levelized greenhouse gas emissions (kg_{CO2eq}/MW h)
LHV	lower heating value (kJ/kg)
LVOP	levelized value of product (units of currency per MW h)
LVOE	levelized value of energy (units of currency per MW h)
m_I	number of indicators in the evaluation matrix
$\dot{m}$	mass flowrate (kg/s or kg/h)
$m_{oil-rel}$	released oil mass (tonnes)
m_{oil-sl}	oil mass in the slick (tonnes)
m_{oil-th}	oil mass in the thick slick (tonnes)
mw	molecular weight (kg/kmol)
n_{col}	number of solar collectors in the solar field
N	number of units/technologies in the scheme
N_{st}	number of stages of compression
N_t	number of turbines in the wind farm
NPV	net present value (units of currency)
p	frequency occurrence
P	power (W or W/m)
p_{down}	downstream pressure (psia or bar)
p_{up}	upstream pressure (psia or bar)
P_0	reference environment pressure (Pa)
P_d	dispatched power (W)
P_f	forecast power (W)
P_r	real power (W)
$Prob_d$	probability of correct dispatching
PrIS	process intensification screening indicator
$\dot{Q}$	heat rate (kW)
r	discount rate
r_n	nominal escalation factor
R	universal gas constant (in kJ/mol K)
R_{sell}	revenue due to product/electricity selling (€)
R_u	specific gas constant (J/kg K)
R_{imb+}	revenue due to positive power unbalance (€)
RI	random index
s	specific entropy (kJ/kg K)
S	specific gravity of gas relative to air
t_{lim}	limit time imposed from simulation tool
T	total number of years in the economic lifetime of the system
T_0	reference environment temperature (K)
T_{02}	mean zero-upcrossing period (s)