
Contents

Preface	xiii
Acknowledgements	xvii
List of figures	xix
List of tables	xxv
Terminologies	xxvii
Example configuration	xxxii
Abbreviations	xxxv
Variables	xxxix
About the author	xliii
1 Overview of wave and tidal development	1
1.1 Introduction	1
1.2 World wave resource	1
1.3 World tidal resource	2
1.4 Influence of the weather	2
1.5 Wave power development	7
1.5.1 Device development	7
1.5.2 Wave device categorisation	7
1.6 Tidal power development	11
1.6.1 Device development	11
1.6.2 Tidal device categorisation	11
1.7 MEC device learning or experience curves	17
1.8 Current world wave and tidal developments	18
1.8.1 Europe	18
1.8.2 The Americas	19
1.8.3 Asia	20
1.8.4 Oceania	20
1.9 Wave and tidal power economic terminology	20
1.9.1 Terminology	20
1.9.2 Cost of installation	22
1.9.3 Cost of energy	23
1.9.4 O&M costs	24
1.9.5 Effect of reliability, availability and maintenance on CoE	25
1.10 Roles	27
1.10.1 General	27
1.10.2 Innovators	27

1.10.3	Governments	28
1.10.4	Regulators	28
1.10.5	Investors	29
1.10.6	Certifiers and insurers	29
1.10.7	Developers	29
1.10.8	Original equipment manufacturers	30
1.10.9	Test facilities	30
1.10.10	Operators and asset managers	30
1.10.11	Maintainers	31
1.11	Summary	31
2	Resource	33
2.1	Introduction	33
2.2	Potential sea wave resource	34
2.2.1	Geographical distribution of resource	34
2.2.2	Wave characteristics	36
2.2.3	Time and frequency domain definition of waves	38
2.2.4	Wave energy calculation	40
2.2.5	Wave energy spectrum	40
2.2.6	Wave prediction and measurement	42
2.3	Potential tidal resource	42
2.3.1	Estuarial sources	42
2.3.2	Non-estuarial tidal streams	44
2.3.3	Tidal characteristics	44
2.4	Resource, location and reliability	46
2.5	Summary	50
3	Reliability theory relevant to wave and tidal devices	51
3.1	Introduction	51
3.2	Background	52
3.2.1	Terminology	52
3.2.2	Failure mechanisms	53
3.2.3	Reliability block diagrams (RBDs) and taxonomy	55
3.2.4	Root causes	59
3.3	Theory	61
3.3.1	Reliability functions	61
3.3.2	Example of reliability data	63
3.3.3	Random and continuous variables	63
3.4	Distributions, point processes, Weibull	66
3.4.1	Probability distribution function	66
3.4.2	Cumulative distribution function	68
3.4.3	Discrete Binomial function	69
3.4.4	Discrete Poisson distribution	70
3.4.5	Continuous exponential distribution	75
3.4.6	Continuous Weibull distribution and its use	75
3.5	The bathtub curve	81

3.6	Basic reliability modelling concepts for MECs	82
3.6.1	General	82
3.6.2	Reliability analysis, machinery versus structure versus taxonomy	83
3.6.3	A reliability modelling concept	84
3.7	Summary	86
4	Reliability prediction method for wave and tidal devices	89
4.1	Introduction	89
4.2	Different reliability prediction and assessment methods	89
4.2.1	General	89
4.2.2	Reliability modelling and prediction (RMP)	90
4.2.3	Failure modes and effects analysis (FMEA)	93
4.2.4	Fault tree analysis (FTA)	93
4.2.5	Monte Carlo simulation	93
4.2.6	Bayesian subjective modelling	94
4.3	Proposed RMP method	94
4.3.1	Reliability modelling and prediction	94
4.3.2	Reliability data from surrogate sources	95
4.3.3	Reliability using environmental modification factors	95
4.4	Reliability prediction model calculations	97
4.4.1	Series network	98
4.4.2	Series parallel network	98
4.5	Summary	99
5	Practical wave and tidal device reliability	101
5.1	Introduction and reliability data collection	101
5.2	Typical root causes and failure modes	101
5.2.1	General	101
5.2.2	Root causes	102
5.2.3	Failure modes	102
5.3	Current reliability knowledge	102
5.3.1	Reliability analysis and industrial reliability data for sub-assemblies	102
5.3.2	Major sub-assemblies	105
5.4	Summary	112
6	Effects of MEC device taxonomy on reliability	115
6.1	Introduction	115
6.2	Wave device configurations	117
6.3	Tidal device configurations	121
6.4	Device configuration taxonomy	125
6.4.1	General concepts and configurations	125
6.4.2	Systems, populations and operating experience	125
6.5	Analysis of device concepts	126
6.6	Summary	129

7	Availability and its effect on the cost of marine energy	131
7.1	Introduction and more terminology	131
7.2	Previous work	134
7.3	Cost of installation	134
7.4	Cost of energy	135
7.5	O&M costs	138
7.6	Effect of reliability, availability and maintenance on CoE	140
7.7	Summary	140
8	Wave and tidal device layout and grid connection	141
8.1	Introduction	141
8.2	MEC arrangements and array cables	141
8.3	Device and array layouts	144
8.4	AC versus DC connection	146
8.5	Off-shore and on-shore substations	147
8.6	Effect of array technology and layout on reliability	148
8.7	Summary	150
9	Design and testing for wave and tidal devices	151
9.1	Introduction	151
9.2	Design and testing example	151
9.3	Methods to improve reliability	153
9.3.1	Reliability results and future devices	153
9.3.2	Design	153
9.3.3	Testing	157
9.4	From high reliability to high availability	161
9.4.1	Relationship of reliability to availability	161
9.4.2	Off-shore environment	161
9.4.3	Detection and interpretation	161
9.4.4	Preventative and corrective maintenance and asset management through-life	161
9.5	Summary	162
10	Operational experience and lessons learnt	163
10.1	Introduction	163
10.2	Wind devices in the United Kingdom, on-shore and off-shore	163
10.3	Wave devices	171
10.4	Tidal devices	171
10.4.1	Lessons learnt	172
10.4.2	Device architecture	173
10.4.3	Fixed versus floating and moored detachable MECs	173
10.4.4	Array configuration	173
10.4.5	Corrosion protection	173
10.5	Summary	174

11 Monitoring and its effect on O&M	177
11.1 Introduction	177
11.2 Monitoring systems	177
11.3 SCADA system	178
11.3.1 Commercially available SCADA systems	179
11.3.2 Examples of WT monitoring through SCADA systems	180
11.4 Structural health monitoring (SHM)	180
11.5 Condition monitoring system (CMS)	181
11.5.1 CMS state-of-the-art	181
11.5.2 Review of CMS techniques	182
11.5.3 Commercially available CMSs	186
11.6 Cost justification	189
11.7 Current limitations and challenges of CM	190
11.8 Examples of monitoring renewable energy sources through CM	192
11.9 Summary	197
12 Overall conclusions	199
12.1 Staff and training	199
12.2 Weather, access and logistics	199
12.3 Device architecture, reliability and testing	199
12.4 Maintenance methods and device changeout	200
12.5 Data management for maintaining off-shore assets	200
Appendix A A tidal poem	201
Appendix B Reliability diagrams of MECs	205
Appendix C MEC reliability data collection based on wind experience	225
Appendix D PSD reliability of key sub-assemblies	237
References	241
Index	247