## Contents

Al	About the editor			xiii	
1	Introduction Hamid Reza Karimi			1	
	Refe	References			
2	Wave loads on monopile-supported offshore wind turbines: current methods and future challenges Enzo Marino, Agota Mockutè, Claudio Borri, and Claudio Lugni			9	
	2.1	Introd	uction	9	
	2.2	Hydro	-aero-servo-elastic coupled simulation models	10	
	2.3	Wave	kinematics	11	
		2.3.1	Governing equations	11	
		2.3.2	Method of solution	12	
		2.3.3	Analytical wave theories	14	
			Nondeterministic representation of waves	16	
		2.3.5	A domain decomposition approach to account for fully		
			nonlinear random waves	17	
	2.4 Hydrodynamic loading models		18		
			Morison equation	18	
			Slender body theory	19	
	~ -		Perturbation theories	19	
	2.5		near resonant effects	20	
			Ringing and springing	20	
			Ringing and secondary loading cycle	21	
	26		Role of wave kinematics and hydrodynamic model	25 25	
	2.6	2.6.1	nic response of an offshore wind turbine Effects of fully nonlinear waves	25 26	
			Effects of different wind conditions	20	
			Limitation of the second-order wave model	28 35	
	2.7			38	
		Acknowledgements			
		References			
	Ren	- chees		39	

3	Numerical and experimental tools for small wind turbine load analysis Karczewski Maciej, Sobczak Krzysztof, Lipian Michal, and Jozwik Krzysztof			
	3.1	Introduction	45	
	3.2	SWT design and development	47	
		3.2.1 Analytical methods	47	
		3.2.2 BET–CFD coupling	51	
		3.2.3 Numerical methods for the WT development	53	
		3.2.4 CFD simulations of the WT	58	
	2.2	3.2.5 BET-CFD simulations of the turbine model in scale	62 65	
	3.3 3.4	Experimental tools for the small wind turbine load analysis Analytical methods for estimation of aeromechanical rotor loads	70	
	3.5	Summary	76	
		erences	78	
4	Structural control concept for load reduction			
		ffshore wind turbines	81	
	Yulii	n Si, Dahai Zhang, and Hamid Reza Karimi		
	4.1	Offshore wind energy development	81	
	4.2	Offshore wind turbine design challenges	83	
		4.2.1 Ultimate loads	85	
		4.2.2 Fatigue loads	85	
		4.2.3 Load reduction solutions	88	
	4.3	Structural control methods	88	
		4.3.1 Tuned mass dampers	89	
		4.3.2 Tuned liquid column dampers	91	
	4.4	4.3.3 Hybrid mass dampers Structural control of offshore wind turbines	92 92	
	4.4	4.4.1 Dynamic modeling	92 95	
		4.4.2 Passive structural control	95 96	
		4.4.3 Active structural control	102	
	4.5	Conclusions	102	
		erences	109	
5	Advanced control of wind turbine system Fanzhong Meng, Jan Wenske, Mohsen Neshati, and Arne Bartschat			
	5.1	A state-of-the-art wind turbine controller	113	
	5.2	Design of controllers for load reduction in wind turbines	115	
		5.2.1 Individual pitch controller	115	
		5.2.2 Effective wind speed estimation	117	
		5.2.3 Feedforward feedback controller based on the effective		
		wind speed estimation	122	

	5.3	Drivet	rain damping	129	
			Traditional drivetrain damping	129	
			Model-based drivetrain active vibration damping	135	
			Sensorless generator control techniques for		
			drivetrain	139	
	Refe	erences		146	
6	Tow	ard far	m-level health management of wind turbine systems:		
			scope for improvements	149	
	Sury	va Teja I	Kandukuri, Kjell G. Robbersmyr, and		
	Han	nid Reza	a Karimi		
	6.1 Introduction				
	6.2	Maint	enance methodologies	151	
			Condition-based maintenance	152	
			Reliability centered maintenance	153	
	6.3		level health management architecture	156	
			On-board CM systems	158	
		6.3.2	SCADA and fault data	158	
		6.3.3	Communication protocol	158	
		6.3.4	Advanced diagnostics and prognostics	159	
		6.3.5	Operation and maintenance database	159	
		6.3.6	Health assessment	160	
		6.3.7	Maintenance advisory	160	
		6.3.8	Maintenance, resource and inventory planning	160	
	6.4	Issues	, challenges and gaps	160	
		6.4.1	Requirements, guidelines and standards	161	
		6.4.2	Database creation and maintenance	161	
		6.4.3	Data analytics and big data	161	
		6.4.4	Advances in prognostics	162	
		6.4.5	Focus on balance-of-system	162	
	6.5	Concl	usion	162	
	Ack	nowled	gment	163	
	Refe	erences		163	
7	Hea	lth moi	nitoring of wind turbine:		
	data	n-based	approaches	169	
	Gua	ng Wan	g, Shen Yin, and Hamid Reza Karimi		
	7.1	Introd		169	
	7.2		mark system and faults description	171	
		7.2.1	Benchmark model	171	
		7.2.2	Fault scenarios	171	
	7.3		t data-driven fault detection design	172	
		7.3.1	Identify parity space directly from measured data	173	
		7.3.2	Select optimal parity vector from parity space	177	

## x Structural control and fault detection of wind turbine systems

	7.3.3 Construct robust residual generators	178		
	7.3.4 A designed robust fault detection scheme	179		
	7.4 Benchmark simulation	180		
	7.5 Conclusions	188		
	References	188		
8	Fault diagnostics for electrically operated pitch systems in offshore			
	wind turbines	193		
	Surya Teja Kandukuri, Van Khang Huynh, Hamid Reza Karimi, and Kjell G. Robbersmyr			
	8.1 Introduction	193		
	8.2 FAST analysis	194		
	8.3 Induction motor behaviour in faulty conditions	196		
	8.4 Faulty machine behaviour in closed-loop	204		
	8.5 Conclusion	208 211		
	Acknowledgements Appendix A	211		
	References	211		
		211		
9	Magnetic bearing for wind turbine power generator shaft:			
	an emulator prototype design for vibration control	215		
	Francisco Palacios-Quiñonero, Leonardo Acho, Josep M. Rossell, and Hamid Reza Karimi			
	9.1 Introduction	215		
	9.2 Small wind turbines characteristics	218		
	9.3 Micro-sized wind turbines: challenges and opportunities	220		
	9.4 Experimental platform for AMB vibration control	222		
	9.4.1 Active magnetic bearings and vibration control	223		
	9.4.2 Experimental platform design	226		
	9.5 Conclusions and final remarks	231 231		
	Acknowledgements Appendix	231		
	References	232		
	Kereichees	233		
10	Condition monitoring and diagnostics of wind turbine power train	237		
	Steven Chatterton and Paolo Pennacchi	_		
	10.1 Background	237		
	10.2 Failure analysis	238		
	10.3 Maintenance policies	240		
	10.4 Condition monitoring and diagnostics	241		
	10.5 Signal processing and fault identification	242 247		
	References	24/		

	-	fault tolerant control wind energy system subject to	253
actuator and sensor faults			253
		e, Elkhatib Kamal, and Maher Kharrat	
11.1	Introdu	ction	253
11.2	RFFTC of WES with DFIG		255
	11.2.1	TS fuzzy model with parameter uncertainties and	
		fuzzy observer	255
	11.2.2	Proposed RFFTC based on FPIEO and FDOS	259
	11.2.3	Proposed RFFTC stability and robustness analysis	262
	11.2.4	WES with DFIG application	262
	11.2.5	Simulations and results	270
11.3	RFSFT	C of WES with DFIG subject to sensor and actuator faults	274
	11.3.1	TS fuzzy plant model with actuator faults, sensor faults	
		and parameter uncertainties	274
	11.3.2	Proposed RFSFTC algorithm based on	
		FPIEO and FDOS	275
	11.3.3	Derivation of the stability and robustness conditions	276
	11.3.4	WES with DFIG application and simulations and results	277
11.4	RDFFT	C of HWDSS subject to actuator and sensor faults	280
	11.4.1	Fuzzy observer scheme for the uncertain system with	
		sensor and actuator faults	280
	11.4.2	Proposed RDFFTC, reference model and stability	
		analysis	281
	11.4.3	HWDSS application and simulations and results	283
11.5	Chapte	r conclusion	290
Refe	rences		291

## Index

295