

Contents

1	Introduction	1
2	The purpose of energy storage systems	3
2.1	Introduction	3
2.2	What storage is used for	3
2.3	Applications of energy storage systems	8
2.4	Conclusion	30
	Chapter summary	32
3	The general description of energy storage systems	33
3.1	Introduction	33
3.2	Mathematical description of structure and function of storage systems	36
3.3	Evaluation of system designs from a financial point of view	69
3.4	Conclusion	82
	Chapter summary	83
4	Introduction to requirement engineering and system design	85
4.1	Introduction	85
4.2	Requirements and system components	85
4.3	General requirements for energy storage systems	99
4.4	Basic components of a storage system	101
4.5	Conclusion	104
	Chapter summary	105
5	Power conversion	106
5.1	Introduction	106
5.2	Electronic components for power conversion	107
5.3	Description of power transfer units from a systems engineering point of view	157
5.4	General requirements for storage systems that need electrical components	162
5.5	Conclusion	165
	Chapter summary	166
6	Mechanical storage systems	167
6.1	Requirements for mechanical storage systems	167
6.2	Energy storage using potential energy part 1: Pumped storage power plants and other concepts	168
6.3	Energy storage by using rotational energy: The flywheel storage	176

6.4	Energy storage using potential energy part 2: The restoring force of a spring	186
6.5	Application example: Upgrading a pumped hydro storage plant for the power market	195
6.6	Conclusion	200
	Chapter summary	201
7	Electrical storage systems	202
7.1	Introduction	202
7.2	Storage of electrical current	202
7.3	Voltage storage systems	213
7.4	Application example: Recuperation of a passenger lift	230
7.5	Conclusion	246
	Chapter summary	246
8	Electrochemical storage systems	248
8.1	Introduction	248
8.2	General considerations on electrochemical storage technologies	248
8.3	Lead acid batteries	275
8.4	Lithium ion batteries	303
8.5	Application example: Residential solar storage system	313
8.6	High-temperature batteries	334
8.7	Redox flow batteries	360
8.8	Conclusion	371
	Chapter summary	371
9	Chemical storage systems	373
9.1	Introduction	373
9.2	General function and requirements	376
9.3	Hydrogen as a storage technology	378
9.4	Methanization: Power to gas or power to liquid	408
9.5	Conclusion	414
	Chapter summary	415
10	Demand side management	416
10.1	Basic functions and requirements	416
10.2	Application example: DSM for a commercial and residential complex	422
10.3	Conclusion	426
	Chapter summary	426
	References	427
	Index	436