
Contents

List of contributors	xxv
Preface	xxvii
Introduction	1
1 Electric power transmission and distribution systems	17
<i>I.A. Erinmez</i>	
1.1 Introduction	17
1.2 Development of transmission and distribution systems	19
1.2.1 Early developments (1880–1930)	19
1.2.2 The development of the transmission grid concept (1930–90)	21
1.2.3 Global developments	23
1.2.4 Recent developments 1990 to date (or 1990 onwards or post 1990)	26
1.3 Structure of transmission and distribution systems	30
1.3.1 Technical factors influencing the structure of transmission and distribution systems	32
1.3.2 Organisational structures	34
1.4 Design of transmission and distribution systems	38
1.4.1 Security of supply	39
1.4.2 Quality of supply	39
1.4.3 Stability	40
1.5 Operation of transmission and distribution systems	41
1.5.1 Operational planning	41
1.5.2 Extended real-time operation	42
1.5.3 Real-time operation	42
1.5.4 Post real-time operation	43
1.6 Future developments and challenges	43
1.6.1 Organisational developments	43
1.6.2 Technical and technological developments	45
1.6.3 Control and communication developments	53
References	54

2	Insulation co-ordination for AC transmission and distribution systems	57
	<i>T. Irwin and H.M. Ryan</i>	
2.1	Introduction	57
2.2	Classification of dielectric stress	61
2.2.1	Power frequency voltage	61
2.2.2	Temporary overvoltages	61
2.2.3	Switching overvoltages	63
2.2.4	Lightning overvoltages	63
2.3	Voltage-time characteristics	63
2.4	Rated withstand voltage levels	64
2.5	Factors affecting switching overvoltages	67
2.5.1	Source configuration	67
2.5.2	Remanent charge	68
2.5.3	Transmission line length	69
2.5.4	Compensation	70
2.5.5	Circuit-breaker pole scatter	70
2.5.6	Point-on-wave of circuit-breaker closure	71
2.6	Methods of controlling switching surges	71
2.6.1	Circuit-breaker pre-insertion resistors	71
2.6.2	Metal oxide surge arresters	72
2.6.3	Circuit-breaker point-on-wave control	77
2.6.4	Comparison of switching overvoltage control methods	78
2.6.5	Application of insulation co-ordination for ultra high-voltage technology	79
2.7	Factors affecting lightning overvoltages entering substations	80
2.7.1	Backflashover	81
2.7.2	Direct strike	84
2.7.3	Attenuation of lightning overvoltage	87
2.8	Methods of controlling lightning overvoltages	87
2.8.1	Location of surge arresters	87
2.9	Conclusions	89
	References	89
3	Applications of gaseous insulants	93
	<i>H.M. Ryan</i>	
3.1	Introduction	93
3.2	Atmospheric air clearances	96
3.2.1	Test areas	96
3.2.2	Sphere gaps	100
3.2.3	Spark gaps	100
3.2.4	Overhead lines and conductor bundles	105
3.2.5	Guidelines for live working	110
3.3	Other gases	111
3.4	Switchgear and GIS	113
3.4.1	Introduction	113
3.4.2	Arc extinction media	116

3.4.3	General dielectric considerations	119
3.4.4	Performance under contaminated conditions	130
3.4.5	GIS service reliability	131
3.4.6	Gas-insulated transmission lines (GIL)	133
3.4.7	Vacuum switches	134
3.5	System modelling for switchgear design applications	136
3.5.1	Field analysis techniques	136
3.5.2	Prediction of breakdown voltages	143
3.6	Summary	148
	Acknowledgements	148
	References	149
4	HVDC and power electronic systems	153
	<i>Gearóid ó hEidhin</i>	
4.1	Introduction	153
4.2	HVDC transmission – a brief overview	153
4.3	General principles	155
4.4	Main components of HVDC links	156
4.4.1	Thyristor valves	156
4.4.2	Converter transformer	158
4.4.3	Control equipment	162
4.4.4	AC filters and reactive power control	163
4.4.5	Smoothing reactor and DC filter	165
4.4.6	Switchgear	166
4.4.7	Surge arresters	168
4.4.8	Valve cooling	168
4.4.9	Auxiliary supplies	169
4.5	Converter building	169
4.6	VSC HVDC	172
4.7	Economics	176
4.8	Power electronic support for AC systems	177
4.8.1	Static var compensators (SVCs)	178
4.8.2	STATCOM	179
4.8.3	Series compensators	180
4.8.4	Unified power flow controller (UPFC)	182
4.9	Power electronics for industrial applications	183
4.10	Conclusion	183
	References	185
5	The implications of renewable energy on grid networks	187
	<i>Adrian Wilson</i>	
5.1	Introduction	187
5.2	Drivers for renewable energy	187
5.2.1	Fossil fuel	187
5.2.2	Nuclear fuels	188

5.3	UK renewable energy resources and technology	188
5.3.1	Power transfers	188
5.3.2	Wind resources	188
5.3.3	Wave resources	189
5.3.4	Tidal resources	190
5.3.5	Biomass resources	193
5.3.6	Network implications from remote resource locations	193
5.3.7	Generator technologies – conventional power stations	193
5.3.8	Generator technologies – full converter wind turbine	195
5.3.9	Generator technologies – partial converter wind turbine	195
5.3.10	Generator technologies – wave machines	195
5.3.11	Generator technologies – tidal machines	195
5.3.12	Generator technologies – biomass-fed generators	196
5.3.13	Generator technologies – microgeneration	196
5.4	Renewable generator technologies – network implications	196
5.4.1	Cost of connections	196
5.4.2	Voltage rise	197
5.4.3	Load flow	197
5.4.4	Fault level	197
5.4.5	Power quality	198
5.4.6	Network extensions	198
5.4.7	Regulation	198
5.4.8	Grid Code issues	199
5.5	Value of energy	199
5.6	Solutions for renewable energy	200
5.6.1	Voltage rise	200
5.6.2	Fault level	200
5.6.3	Fault current limiters	201
5.6.4	Principles of superconducting fault current limiters	201
5.6.5	Fault current limiters	202
5.6.6	Resistive fault current limiters	202
5.6.7	Shielded core fault current limiters	203
5.6.8	Pre-saturated core fault current limiters	203
5.6.9	Load flow	205
5.6.10	Energy storage	205
5.6.11	Distributed intelligence in networks	206
5.7	Conclusions	206
	References	206
	Postscript note – by H.M. Ryan	209

6 High-voltage cable systems 211

A.L. Barclay

6.1	Introduction	211
6.2	Elementary theory	212
6.2.1	Voltage, electric field and capacitance	212
6.2.2	Current, magnetic field and inductance	214

6.3	Historical development	214
6.3.1	Early telegraph cables	215
6.3.2	Early lighting systems	215
6.3.3	Flexible cables	215
6.3.4	Impregnated cables and the renaissance of high voltage	216
6.3.5	Pressure-assisted (gas) cables	216
6.3.6	Fluid-filled cables	217
6.3.7	Polymeric cables	217
6.3.8	Polypropylene-paper laminate	218
6.4	Features of real cables	218
6.4.1	The conductor	218
6.4.2	The insulation system	222
6.4.3	Multi-core and multi-function cables	228
6.4.4	Outer layers	229
6.4.5	Installation	232
6.5	Current ratings	234
6.5.1	Time-dependent ratings	235
6.5.2	Factors affecting ratings	236
6.6	Accessories	243
6.6.1	Terminations	243
6.6.2	Joints	246
6.6.3	Other accessories	249
6.7	Direct current and subsea cable systems	249
6.7.1	Applications of AC and DC transmission	249
6.7.2	Subsea cable configurations	250
6.7.3	Insulation systems	252
6.7.4	Manufacture	254
6.7.5	Installation	255
6.7.6	Accessories	255
6.8	Standards	256
6.9	Testing	258
6.9.1	Development testing	258
6.9.2	Type testing	259
6.9.3	Prequalification testing	260
6.9.4	Factory acceptance testing	261
6.9.5	After-laying tests	262
6.9.6	In-service monitoring	266
6.9.7	Testing for periodic maintenance	267
6.9.8	Fault location	268
6.10	Future directions	269
	References	271

7	Gas-filled interrupters – fundamentals	275
	<i>G.R. Jones, M. Seeger and J.W. Spencer</i>	
7.1	Introduction	275
7.2	Principles of current interruption in HV systems	275
7.2.1	System-based effects	277
7.2.2	Circuit-breaker characteristics	280
7.3	Arc control and extinction	281
7.3.1	Gas-blast circuit-breakers	283
7.3.2	Electromagnetic circuit-breakers	285
7.3.3	Dielectric recovery	287
7.4	Additional performance affecting factors	288
7.4.1	Metallic particles	289
7.4.2	High-frequency electrical transients	290
7.4.3	Trapped charges on PTFE nozzles	290
7.5	Other forms of interrupters	292
7.5.1	Domestic circuit-breakers	292
7.5.2	Oil-filled circuit-breakers	293
7.5.3	Vacuum interrupters	293
7.6	Future trends	294
7.6.1	Other gases	295
7.6.2	Material ablation and particle clouds	297
7.6.3	New forms of electromagnetic arc control	298
7.6.4	Direct current interruption	299
	References	300
8	Switchgear design, development and service	303
	<i>S.M. Ghufuran Ali</i>	
8.1	Introduction	303
8.1.1	SF ₆ circuit-breakers	303
8.1.2	Sulphur hexafluoride	305
8.2	Interrupter development	305
8.2.1	Two-pressure system	306
8.2.2	Single-pressure puffer-type interrupters	306
8.3	Arc interruption	310
8.3.1	Fault current	310
8.3.2	Capacitive and inductive current switching	312
8.3.3	Reactor switching	314
8.3.4	Arc interruption: gas-mixtures	315
8.4	Third-generation interrupters	316
8.5	Dielectric design and insulators	318
8.6	Mechanism	318
8.7	SF ₆ live- and dead-tank circuit-breakers	319
8.7.1	Basic GIS substation design	319
8.8	Opening and closing resistors/metal-oxide surge arresters	324
8.8.1	Opening and closing resistors	324

8.8.2	Closing resistors/metal-oxide surge arresters	325
8.8.3	Main features of metal-oxide surge arresters (MOSA)	326
8.9	Disconnecter switching	327
8.10	Ferroresonance	328
8.11	System monitoring	330
8.11.1	Monitoring during installation and in service	330
8.11.2	Continuous monitoring	331
8.11.3	Periodic monitoring	331
8.12	Insulation co-ordination	332
8.12.1	Introduction to appendices	332
8.13	Further discussions and conclusions	334
	Acknowledgements	335
	References	336
	Appendices	337
A	Some historic observations	337
B	SF ₆ circuit-breakers in the UK plus a perspective from USA	340
C	Relevant strategic IEC Standard reports	342
D	Update of some recent CIGRE activities relating Appendices D and E to Substations (SC B3) and also (SC B5) – compiled from CIGRE publications by H.M. Ryan	343
E	Residual life concepts, integrated decision processes for substation replacement and an overview of CIGRE work on AM themes – compiled by H.M. Ryan	349
9	Distribution switchgear	355
	<i>B.M. Pryor</i>	
9.1	Introduction	355
9.2	Substations	357
9.2.1	Substation types	357
9.2.2	Substation layouts	359
9.3	Distribution system configurations	361
9.3.1	Urban distribution systems	361
9.3.2	Rural distribution systems	363
9.4	Ratings	364
9.4.1	Rated current	365
9.4.2	Rated short-circuit-breaking current	365
9.4.3	Rated short-circuit-making current	365
9.4.4	Rated asymmetrical breaking current	365
9.4.5	Rated short-time current	365
9.4.6	Rated voltage	366
9.4.7	Rated insulation withstand levels	366
9.4.8	Rated transient recovery voltage	366
9.5	Switching equipment	366
9.5.1	Circuit-breakers	367
9.5.2	Distribution circuit-breaker types	369
9.5.3	Disconnectors	376

9.5.4	Earth switches	378
9.5.5	Switches	378
9.5.6	Switch disconnector	379
9.5.7	Switch fuse	379
9.5.8	Fuse switch	379
9.5.9	Fuses	380
9.5.10	Contactors	382
9.5.11	Ring main units	382
9.6	Circuit protection devices	383
9.6.1	Surge arresters	383
9.6.2	Instrument transformers	385
9.7	Switchgear auxiliary equipment	387
9.8	SF ₆ handling and environmental concerns	387
9.8.1	SF ₆ breakdown products	387
9.8.2	SF ₆ environmental concerns	388
9.9	The future (as perceived in 2000 and again in 2011)	389
9.9.1	The future 1 – by B.M. Pryor in 2000	389
9.9.2	The future 2 – by H.M. Ryan in 2011	391
	Disclaimer	396
	Summary	396
	References	397
	Appendices – by H.M. Ryan	398
	A Additional CIGRE references	398
	B Distribution systems and dispersed generation (after CIGRE [8]) – summary of key CIGRE information mainly from SC C6 2011 AGM [8] – compiled by H.M. Ryan	399
10	Differences in performance between SF₆ and vacuum circuit-breakers at distribution voltage levels	407
	<i>S.M. Ghufra Ali</i>	
10.1	Introduction	407
10.2	Circuit-breaker	407
10.3	Vacuum circuit-breaker	408
10.4	SF ₆ gas circuit-breakers	409
10.5	Puffer circuit-breaker	409
10.6	Rotating-arc circuit-breaker	412
10.7	Auto-expansion circuit-breaker	412
10.8	Operating mechanism	413
10.9	Choice of correct circuit-breaker for special switching duties	413
10.10	Capacitive and inductive current switching	414
10.11	Circuit-breakers for generator circuit switching	415
10.11.1	DC offset	416
10.11.2	Current chopping and reignition	416
10.12	Synchronised switching	416
10.13	Conclusions and some future developments	417

CIGRE perception of future developments: prepared and compiled by H.M. Ryan	418
Acknowledgements	419
Bibliography	420
Appendices	421
A Relevant strategic IEC Standard reports	421
B The impact of new functionalities on substation design (relating to CIGRE published work) – abridged and compiled by H.M. Ryan	422
11 Life management of electrical plant: a distribution perspective	425
<i>John Steed</i>	
11.1 Introduction	425
11.2 Reliability	426
11.2.1 Sources of data	426
11.2.2 Typical distribution company requirements for data	428
11.2.3 Case studies using data	428
11.2.4 The bath tub curve	430
11.2.5 Practical example – distribution transformers	431
11.2.6 Human factors in plant reliability	432
11.2.7 Conclusions on reliability	434
11.3 Condition monitoring	435
11.3.1 Definitions	435
11.3.2 Benefits of condition monitoring	435
11.3.3 Application to equipment	436
11.3.4 What condition monitoring information can tell us about asset management	445
11.3.5 Condition assessment leading to asset replacement	447
11.3.6 The new working environment – users’ requirements	449
11.3.7 Condition monitoring – the future	450
11.4 Plant maintenance	450
11.4.1 General techniques	450
11.4.2 Enhanced maintenance	452
11.4.3 Reliability-centred maintenance (RCM)	453
11.4.4 Condition-based maintenance (CBM)	454
11.5 Working plant harder	455
11.5.1 Towards a risk-based strategy – the reasons why	455
11.5.2 Risk assessment – FMEA and FMECA	455
11.5.3 Working switchgear harder	457
11.5.4 Working transformers harder	457
11.6 Future trends in maintenance	458
11.7 A holistic approach to substation condition assessment	459
11.8 Retrofit, refurbish or replace?	460
11.9 Current challenges	460
11.10 A standard for asset management	462

11.11	The impact of smart grids on asset management	463
11.12	Information management	463
11.13	Conclusions	464
	References	464
12	High-voltage bushings	467
	<i>John S. Graham</i>	
12.1	Introduction	467
12.2	Types of bushings	467
12.2.1	Non-condenser bushings	467
12.2.2	Condenser bushings	469
12.3	Bushing design	472
12.3.1	Air end clearance	473
12.3.2	Oil-end clearance	477
12.3.3	Radial gradients	478
12.4	Bushing applications	478
12.4.1	Transformer bushings	478
12.4.2	High-current bushings	481
12.4.3	Direct connection to switchgear	481
12.4.4	Switchgear bushings	483
12.4.5	Direct current bushings	484
12.5	Testing	486
12.5.1	Capacitance and dielectric dissipation factor measurement	487
12.5.2	Power frequency withstand and partial discharge measurement	487
12.5.3	Impulse voltage tests	489
12.5.4	Thermal stability test	489
12.5.5	Temperature rise test	490
12.5.6	Other tests	490
12.6	Maintenance and diagnosis	490
	References	492
13	Design of high-voltage power transformers	495
	<i>A. White</i>	
13.1	Introduction	495
13.2	Transformer action	495
13.3	The transformer as a circuit parameter	497
13.4	Core- and shell-form constructions and components	498
13.4.1	The core	499
13.4.2	The windings	503
13.4.3	Cooling	508
13.4.4	Insulation	509

13.4.5	Tank	510
13.4.6	Bushings	510
13.4.7	On-load tap-changer	511
13.5	Design features	512
13.5.1	Dielectric design	512
13.5.2	Electromagnetic design	515
13.5.3	Short-circuit forces	517
13.5.4	Winding thermal design	518
13.6	Transformer applications	519
13.6.1	Power station transformers	520
13.6.2	Transmission system transformers	521
13.6.3	HVDC converter transformers	521
13.6.4	Phase-shifting transformers	523
13.6.5	Industrial transformers	525
13.6.6	Railway transformers	526
13.7	A few predictions of the future	527
	References	528
14	Transformer user requirements, specifications and testing	529
	<i>S. Ryder and J.A. Lapworth</i>	
14.1	Introduction	529
14.2	Specification of user requirements	530
14.2.1	Need for user specifications	530
14.2.2	Functional and design specifications	530
14.2.3	Specifications and standards	531
14.2.4	Specification content	531
14.2.5	Guidance on specifications	535
14.3	Supplier selection	535
14.3.1	Industry changes	535
14.3.2	Timing	535
14.3.3	Format	535
14.3.4	Aims	536
14.3.5	Main elements of process	536
14.4	Testing	538
14.4.1	Classification of tests	538
14.4.2	Performance tests	539
14.4.3	Thermal tests	540
14.4.4	Dielectric tests	542
14.4.5	Short-circuit withstand	547
14.4.6	Condition assessment testing	548
14.5	Operation and maintenance	548
14.5.1	Limitations on transformer life	548
14.5.2	Preventive and corrective maintenance	549
14.5.3	Time- and condition-based maintenance	549

14.5.4	Oil tests	550
14.5.5	Electrical tests	550
14.6	Concluding remarks	551
	Bibliography	552
15	Basic measuring techniques	555
	<i>Ernst Gockenbach</i>	
15.1	Introduction	555
15.2	Measuring system	555
15.3	Amplitude measurements	561
15.3.1	Direct voltage	561
15.3.2	Alternating voltage	563
15.3.3	Impulse voltage	567
15.3.4	Impulse current	571
15.4	Time parameter	572
15.5	Measuring purposes	573
15.5.1	Dielectric tests	573
15.5.2	Linearity tests	573
15.6	Summary	573
	References	574
16	Basic testing techniques	575
	<i>Ernst Gockenbach</i>	
16.1	Introduction	575
16.2	Recommendations and definitions	576
16.3	Test voltages	578
16.3.1	DC voltage	578
16.3.2	AC voltage	580
16.3.3	Impulse voltage	584
16.4	Impulse current	591
16.5	Test conditions	592
16.6	Summary	597
	References	598
17	Partial discharge measuring technique	599
	<i>Ernst Gockenbach</i>	
17.1	Introduction	599
17.2	Physical background of partial discharges	600
17.3	Requirements on a partial discharge measuring system	604
17.4	Measuring systems for apparent charge	606
17.5	Calibration of a partial discharge measuring system	608
17.6	Examples of partial discharge measurements	608
17.6.1	Partial discharge measurement on high-voltage transformers	609

17.6.2	Partial discharge measurement and location on high-voltage cables	609
17.6.3	Partial discharge measurement on high-voltage gas-insulated substations	611
17.6.4	Development of recommendation	613
17.7	Summary	614
	References	614
18	Digital measuring technique and evaluation procedures	615
	<i>Ernst Gockenbach</i>	
18.1	Introduction	615
18.2	Requirements on the recording device	616
18.3	Requirements on the evaluation software	619
18.4	Application of digital recording systems	620
18.4.1	DC and AC voltage measurements	620
18.4.2	Impulse voltage or current measurements	621
18.4.3	Partial discharge measurements	623
18.5	Application examples of evaluation procedures	626
18.6	Conclusions	629
	References	629
19	Fundamental aspects of air breakdown	631
	<i>J. Blackett</i>	
19.1	Introduction	631
19.1.1	History	633
19.1.2	High-voltage laboratory testing	634
19.2	Pre-breakdown discharges	635
19.2.1	Electron avalanches	635
19.2.2	Streamer discharges	635
19.2.3	Leaders	635
19.3	Uniform fields	636
19.3.1	Electron avalanches in uniform fields	636
19.4	Non-uniform fields	640
19.4.1	Direct voltage breakdown	641
19.4.2	Alternating voltage breakdown	642
19.4.3	Impulse breakdown	644
19.4.4	Leaders	644
19.4.5	Sparkover, breakdown, disruptive discharge	645
19.5	The 'U-curve'	647
19.5.1	The critical time to breakdown	654
19.6	The gap factor	655
19.6.1	Test procedures	656
19.6.2	Air gaps of other shapes	658
19.6.3	Sparkover under alternating voltages	659
19.6.4	Sparkover under direct voltages	659

19.7	Flashover across insulator surfaces in air	662
19.8	Atmospheric effects	664
19.8.1	Introduction	664
19.8.2	Density effects	664
19.8.3	Humidity effects	665
19.8.4	Application of correction factors	665
19.8.5	Air density correction factor k_1	666
19.8.6	Humidity factor correction k_2	666
19.8.7	Other atmospheric effects	668
19.9	New developments	669
19.9.1	UHV at high altitudes	669
19.9.2	Testing transformers	669
19.9.3	Future work	672
	References	672
20	Condition monitoring of high-voltage transformers	675
	<i>A. White</i>	
20.1	Introduction	675
20.2	How do faults develop?	676
20.3	Which parameters should be monitored?	677
20.4	Continuous or periodic monitoring	677
20.5	Online monitoring	678
20.6	Degrees of sophistication for transformer monitors	678
20.7	What transformer parameters can be monitored?	681
20.8	Basic monitors	682
20.9	On-load tap-changer (OLTC) module	683
20.10	Insulation module	685
20.11	Bushing module	685
20.12	Cooling module	687
20.13	Advanced features measurements and analyses	688
20.14	Partial discharge monitoring	689
20.15	Temperature measurement	690
20.16	Chemical parameters	690
20.17	Dielectric parameters	691
20.18	Conclusions	691
20.19	Further reading	692
	References	692
21	Integrated substation condition monitoring	693
	<i>T. Irwin, C. Charlson and M. Schuler</i>	
21.1	Introduction	693
21.2	The evolution of condition monitoring systems	696
21.2.1	Periodic monitoring, 1960–1990	697
21.2.2	Basic discrete online monitoring, 1990–1999	697

21.2.3	More intelligent discrete monitoring, 2000–2009	698
21.2.4	Integrated substation condition monitoring (2010 onwards)	698
21.3	Objectives of condition monitoring	700
21.4	Application to key substation equipment	701
21.5	The substation environment	701
21.6	Condition monitoring platform	703
21.6.1	Data acquisition systems	704
21.6.2	Sensors and transducers	705
21.6.3	Conversion module	705
21.6.4	Interface module	705
21.6.5	Data acquisition module	705
21.6.6	Control PC module	705
21.6.7	Communication module	706
21.7	Data acquisition, analysis and diagnostics	706
21.7.1	Developing a common monitoring platform	707
21.7.2	Specification of the node unit data acquisition system	711
21.8	GDM node unit overview	711
21.8.1	Data collection	712
21.8.2	Predictive alarms and SF ₆ gas inventory	713
21.8.3	Maintenance	715
21.9	CBM node unit overview	716
21.9.1	Signals measured and recorded	716
21.9.2	System alarms	718
21.9.3	Data storage and display	719
21.10	PDM node unit overview	722
21.10.1	PDM node unit data collection	724
21.10.2	Node unit sequencer controls	724
21.10.3	Node unit noise monitoring and alarm control	725
21.10.4	Node unit system diagnostics	727
21.11	Power transformer monitoring	727
21.11.1	Sensors for dissolved gas analysis	731
21.11.2	Sensors for tap-changer monitoring	732
21.12	Cable monitoring	732
21.12.1	Sensors for cable monitoring	733
21.13	Surge arrester monitoring	734
21.14	ISCM system overview	736
21.14.1	Substation gateway	736
21.14.2	CM module: PD monitoring	740
21.14.3	CM module: gas density monitoring	744
21.15	ISCM systems going forward	747
21.16	Concluding remarks	748
	Acknowledgements	749
	References	749

Appendices	751
A Gas density monitoring transducer options	751
B Circuit breaker monitoring data sampling rates	752
C Partial discharge monitoring data sampling rates	752
D Disconnecter and earth switch monitoring data sampling rates	752
22 Intelligent monitoring of high-voltage equipment with optical fibre sensors and chromatic techniques	755
<i>G.R. Jones and J.W. Spencer</i>	
22.1 The nature of intelligent monitoring	755
22.2 The basis of chromatic monitoring	756
22.3 Online monitoring of high-voltage equipment using optical fibre chromatic techniques	758
22.3.1 Optical fibre chromatic sensors	758
22.3.2 Examples of chromatic optical fibre sensors for high-voltage systems	759
22.3.3 Time and frequency domain chromatic processing of optical fibre sensor data	761
22.4 Chromatic assessment of the degradation of high-voltage insulation materials	768
22.4.1 Chromatic characterisation of partial discharge signals (M. Ragaa)	768
22.4.2 Offline assessment of high-voltage transformer oils with chromatic techniques (E. Elzazoug and A.G. Deakin)	773
22.5 Conclusions	780
Acknowledgements	781
References	781
Appendix A	785
23 Some recent ESI developments: environmental, state of art, nuclear, renewables, future trends, smart grids and cyber issues	787
<i>H.M. Ryan</i>	
Preface	787
23.1 Introduction	788
23.2 International takeovers in UK power sector and possible impacts	791
23.2.1 Warning: kid gloves treatment	793
23.3 Some aspects of renewable energy development in the UK	796
23.3.1 Energy-mix and perceived renewable energy costs (2004–10)	796
23.3.2 Renewable energy vs landscape calculations (<i>The Sunday Times</i> , 20/11/11)	799
23.3.3 UK energy storage: call to build a series of dams to store power from wind turbines (after D. MacKay) (Jonathan Leake, <i>The Sunday Times</i> , 18/3/12)	800

23.3.4	Press articles: Some very public energy discussions (commentaries on articles by D. Fortson <i>et al.</i> , <i>The Times</i> , 2010–12)	803
23.4	UK government's recent wind of change	808
23.5	Nuclear power plants: recent events and future prospects	810
23.5.1	Fukushima nuclear accident: short-term impact on global developments	810
23.5.2	Future nuclear developments	811
23.5.3	Future prospects of 'new-build' nuclear plants overseas	815
23.6	Some aspects of carbon trading	819
23.6.1	Coal-fired to co-fired stations in the UK to avoid paying rising climate taxes (after Danny Fortson, <i>The Sunday Times</i> , Energy Environment, 26/2/12)	820
23.6.2	Frying note: storage energy back-up	823
23.7	A new green technology: carbon capture and storage (CCS) (Tim Webb, <i>The Times Business Dashboard</i> , 29/3/12)	825
23.7.1	Some committed CCS developments worldwide	825
23.8	Recent developments in UK Network/European Grid links	833
23.8.1	New UK/International DC cable links	833
23.8.2	Proposal case for a North Sea super grid (NSSG)	833
23.8.3	Challenges facing AC offshore substations for wind farms and preliminary guidelines for design and construction	839
23.8.4	Network upgrades and some operational experiences	844
23.9	Some UK operational difficulties with wind farms	845
23.9.1	Wind farms paid £900,000 to switch off (1)	845
23.9.2	Storm shut-down is blow to the future of wind turbines (2) (Jon Ungoed-Thomas and Jonathan Leake, <i>The Sunday Times</i> , 11/12/11)	846
23.9.3	Energy speculators now bet on wind farm failures (3) (J. Gillespie, <i>The Times</i> , December 2011)	847
23.9.4	Millions paid to wind farm operators to shut down (4)	848
23.9.5	Clean energy financial support; impact of Scotland leaving the Union after an independence vote in 2014 (5) (Karl West, <i>The Sunday Times</i> , 22/1/2012)	850
23.9.6	Crown Estate: Scottish assets worth arguing over in independence debate [6] (Deirdre Hipwell, <i>The Times</i> , 21/06/2012, pp. 34–5)	851
23.9.7	Some poor wind farm performance statistics	852
23.9.8	'Flying wind farms pluck energy out of the blue', states Gillespie in <i>The Sunday Times</i> (08/07/12, p. 7)	854
23.10	UK air-defence radar challenged by wind turbines	854
23.11	Noise pollution: wind turbine hum (<i>The Sunday Times</i> , 18/12/11)	855
23.12	Balancing fluctuating wind energy with fossil power stations	857

23.13	Future developments including smart grids	858
23.13.1	US study by Gellings <i>et al.</i> from EPRI [30] (1)	860
23.13.2	Some CIGRE perspectives of energy activities and future development [35] (2)	863
23.14	Discussion and conclusions	877
23.14.1	Discussion	877
23.14.2	Conclusions	890
	References	891
	Appendices	895
A	Cyber-crime and cyber-security	895
B	Cyber-crime	895
C	CIGRE: Treatment of information security for electric power utilities	901