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Advanced Control of AC/DC Power Networks

*System of Systems Approach
Based on Spatio-temporal Scales*

Abdelkrim Bennaib

ISTE

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Advanced Control of AC/DC Power Networks

Foreword

At the end of the 19th Century, Thomas Edison and Nikola Tesla were very invested in the famous AC versus DC power battle for the power networks development, i.e. *War of the Currents*.

During the 20th Century and today, power networks are mainly based on an AC supply.

Now, at the beginning of the 21st Century, the continuous development of the increasingly renewable energy sources (RESs) interconnected into power networks may reveal the following strategic question:

– *What do we see as the future of AC and DC power networks?*

The author of this book tries to answer this fundamental question to ensure security of the electricity supply in the world by providing an in-depth thinking based on a new approach called “Systems of Systems”, using advanced control algorithms. Moreover, the concept of “Plug and Play” is also introduced by the author to satisfy industrial objectives in relation with the development of new electric power grids integrated massive RESs and plug-in electric vehicles (PEVs).

The large experience of the author in R&D in the industry, supplemented by a significant background in academic research and executive teaching, give to this book a particular attractiveness.

The multi-terminal direct-current (MTDC) grids, using power electronics-based systems, are investigated by the author in terms of

modeling, analysis and advanced control in order to define the optimized building blocks requested for “mixed” AC & DC future power networks.

From the theoretical point of view, fully in relation with the stability analysis of AC and DC grids, the equivalence of the AC “swing equation” and the DC “swing equation” is described. This new analytical tool appears as a major added value of the presented works.

This book has also the ambition to bring together the academic and industrial communities in the areas of:

- power networks,
- automatic control,
- power electronics,
- electrical machines,

in order to propose new disruptive technologies to build the future mixed AC and DC power networks.

Many fields of scientific investigations are present in this work and open the door for future debates on transmission and distribution grids, guaranteeing the security of the electricity delivery and minimizing the risk of blackouts.

To conclude, this book is certainly a reference for the advanced control of “mixed” AC and DC power networks in the future.

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Preface

Nowadays, more than ever, the power engineering domain is facing huge challenges. It is showing an increasing interest in intermittent renewable energies which are imposing major technical limitations. The use of these resources must be accompanied by secure, indigenous, sustainable, clean and competitive operation. A realistic solution is wind power. Many countries are now starting to install wind turbines offshore. In Europe, the offshore wind potential is able to cover seven times the whole demand. High-voltage alternating current (HVAC) provides the simplest and most economic connection method for short distances. Because the distance of the offshore farms exceeds 100–150 km, the transmission with high-voltage direct current (HVDC) is economically inevitable. Thus, HVDC systems offer interesting prospects if the power grid is well controlled.

For power transmission, the DC grid would overlay the existing AC grid, like a national motorway system connects to smaller local road systems. In power distribution, DC grids will emerge from more constrained grid codes as they will be imposed by distribution operators for PV integration. One of the main challenges for DC deployment is the handling of multi-terminal DC (MTDC) grids. At the heart of the thinking behind the MTDC grids is, precisely, the notion of “system of systems”. Indeed, a key component of systems of systems control and operations is the notion of time scales. For example, the primary control in AC grids is a global but distributed control in which the notion of “Think Globally and Act Locally” (TGAL) is applied. This time scales control philosophy will enable the “plug-and-play” property which is mandatory when dealing with networked systems. For example, in a flock of birds or school of fish, each individual keeps a certain distance and follows the congener in front. The result is that each individual acts like the

whole group, while the whole group acts like an individual (droop control: global but distributed control). The individual can leave or join the group without altering its global behavior (plug-and-play). In addition to time scales, space scale considerations need to be taken into account with new modeling, control and observation tools and techniques.

Abdelkrim BENCHAIIB
July, 2015

List of Figures

INTRODUCTION

I.1. Blackouts in power networks.	xix
I.2. Blackout in Western Europe, 4th November 2006: frequency split and resynchronization process (source: ENTSOE)	xx
I.3. Challenges for power network of the future	xxi
I.4. Cost of HVDC link compared to HVAC	xxiii
I.5. New highways for power grid of the future, courtesy of Desertec	xxiii
I.6. Power profile provided to the network	xxiv
I.7. PV production unit with energy storage system (ESS).	xxiv
I.8. DC grid for PV integration with ESS connected to the power grid	xxv
I.9. Hybrid (AC and DC) power network of the future.	xxvi
I.10. French power network hierarchization	xxvii

CHAPTER 1

1.1. Two-terminal VSC system	2
1.2. Power and current directions.	4
1.3. Monopolar symmetrically grounded VSC-MTDC system	5
1.4. Single-phase VSC representation	7
1.5. PQ closed-loop VOC implemented on the dq synchronous frame	9
1.6. Current controller structure – VOC based on dq synchronous frame	10

1.7. V_{dc} -Q closed-loop VOC implemented on the dq synchronous frame	14
1.8. DC voltage control structure.	14
1.9. DC voltage droop proportional controller	15

CHAPTER 2

2.1. Time scale control structure for multi-terminal DC grids	18
2.2. Three-terminal HVDC	21
2.3. Illustration of: a) slack bus and b) P-controller	22
2.4. Three-terminal HVDC under master/slave control strategy	22
2.5. Voltage margin strategy illustration	23
2.6. Operating point in voltage margin strategy	23
2.7. A second operating point in voltage margin strategy	24
2.8. Voltage droop characteristics: a) voltage/power and b) voltage/current	25
2.9. Voltage droop characteristics: a) voltage limitation and b) power limitation	28
2.10. Power limitation: a) for a node which is capable of working only as a generator ($P > 0$) and b) for a node which is capable of working only as a load ($P < 0$)	28
2.11. Voltage droop characteristics with dead-band: a) voltage dead-band and b) power dead-band	29
2.12. Voltage droop characteristics with undead-band: a) voltage undead-band and b) power undead-band	30
2.13. Monopolar symmetrically grounded VSC substation connected to an MTDC network.	32
2.14. i, j connection.	33
2.15. Current flowing to the shunt resistance.	33
2.16. Geometrical illustration of the Newton–Raphson technique.	36
2.17. Chart of the power flow calculation: first method	37
2.18. NR flow chart for the first power flow resolution method.	41
2.19. Chart of the power flow calculation with droop characteristics: second method	42
2.20. NR flow chart for power flow calculation taking into account voltage/power droop.	44
2.21. Three-terminal DC grid	46
2.22. Three-terminal HVDC before the power flow resolution	46

2.23. Illustration of the power flow results of a three-terminal HVDC	48
2.24. DC grid power response to power disturbance at node 1 with master/slave control strategy	48
2.25. DC grid voltage response to power disturbance at node 1 with master/slave control strategy	49
2.26. DC grid power voltage responses to power disturbance at node 1 with voltage margin control strategy	50
2.27. DC grid power response to power disturbance at node 1 with voltage/power droop control strategy	51
2.28. DC grid voltage response to power disturbance at node 1 with voltage/power droop control strategy	51
2.29. Power balancing of a three-terminal DC grid with primary and secondary control strategies	53

CHAPTER 3

3.1. Wide area monitoring system (WAMS)	58
3.2. PMU-based WAMS and network-model-based EMS hybrid solution	60
3.3. Real power flowing on a major transmission line during the Western North American power system breakup of 1996	61
3.4. Response to a fault cleared in t_{c1} seconds, stable case (left), in t_{c2} seconds unstable case (right)	64
3.5. Three-interconnected generators model with Simpower system	75
3.6. Interconnected generators model (swing equation) with Matlab/Simulink	78
3.7. Post-fault frequency responses of a) Simpower system, b) nonlinear swing equation model and c) linearized swing equation model	79
3.8. Post-fault electrical power of a) Simpower system, b) nonlinear swing equation model and c) linearized swing equation model	80
3.9. Post-fault angle differences of a) Simpower system, b) nonlinear swing equation model and c) linearized swing equation model	81
3.10. Three-node interconnected AC power network	82
3.11. Simulation results for a nonlinear model and linearized model	85

CHAPTER 4

4.1. Simulation results of the linear model without/with command	91
4.2. Simulation results for the three-machine system and average model	94
4.3. Interconnection of two power systems – regions r_1 and r_2	95
4.4. Power transfer between regions 1 and 2 (nonlinear model)	97
4.5. Power transfer between regions 1 and 2 (average model)	97
4.6. Frequency (rd/s) in region 1: nonlinear model a), average model b)	98
4.7. Frequency (rd/s) in region 2: nonlinear model a), average model b)	98
4.8. Time derivative of the frequency in regions 1 and 2	98
4.9. Two-terminal DC grid	99
4.10. Three-terminal DC grid	101
4.11. DC station	102
4.12. Two-terminal DC grid for electric power term calculation	104
4.13. Power part of a synchronverter – a three-phase inverter, including LC filter	106
4.14. Electronic (control) part of a synchronverter	106

CONCLUSION

C.1. School of fish	111
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APPENDIX 3

A3.1. Simulation of generator (2) with Simpower system	121
A3.2. Power flow computation with PowerGUI	122

List of Tables

CHAPTER 2

2.1. Summary of the control strategy gain settings	31
2.2. Lineic resistance and the length of the cables (links).	46
2.3. DC power injections and DC voltage values at different nodes	47
2.4. Transmitted DC power between the connected nodes.	47
2.5. Power losses in the shunt resistance at the different nodes	47

CHAPTER 3

3.1. Summary of stability approaches	67
3.2. Generator parameters	76
3.3. Transformer parameters	76
3.4. Transmission line parameters	76
3.5. Load parameters	76

CHAPTER 4

4.1. Simulation data for three interconnected machines	94
4.2. Simulation scenario for inter-region connection	97
4.3. Similarities between AC and DC systems	105

Introduction and Problem Positioning

I.1. Today's power network conditions

Operating closer to their limits, AC power grids are more vulnerable and subject to instabilities than ever before. Controlling and operating them with a given degree of reliability will be our main challenge in power networks of the future. The warning signs are shown in Figure I.1.

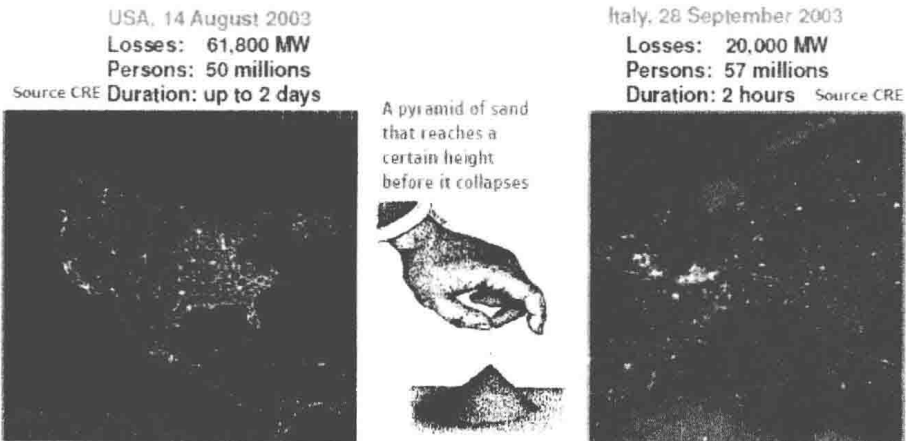


Figure I.1. *Blackouts in power networks*

In 2003, blackouts cost the US economy \$6 billion. In the same year, they were responsible for four deaths in Italy. The power failures across Western Europe in 2006 caused by a transmission line shutdown in Germany underlined the risks of outages crossing national boundaries (see [ALS 14] and references therein).

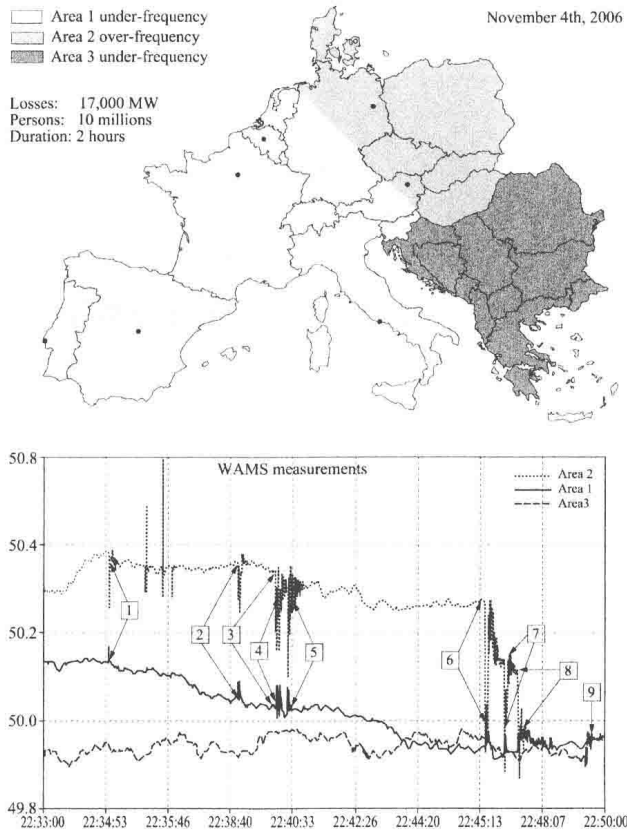


Figure I.2. Blackout in Western Europe, 4th November 2006: frequency split and resynchronization process (source: ENTSOE)

During this latter event, the UCTE grid was split into three islands at different frequencies. In the 2 hours, it took to resynchronize, some 15 million people were affected, and some 17,000 MW of power generation had to be curtailed.

Yet a certain school of thought contends that blackouts are natural network behavior: “It’s like a pyramid of sand that reaches a certain height before it collapses, because that’s the nature of sand (see Figure I.1 and references in [DOB 12]). There have been serious attempts to develop blackout prevention strategies, but blackouts and brownouts still occur and will continue to do so. Prevention is merely containment.” Sooner or later, the variety and complexity of loads and operations will reach AC network limits.