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Advanced Control of AC/DC Power Networks

System of Systems Approach Based on Spatio-temporal Scales

Abdelkrim Benchaib

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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 BENCHAIB
July, 2015

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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.

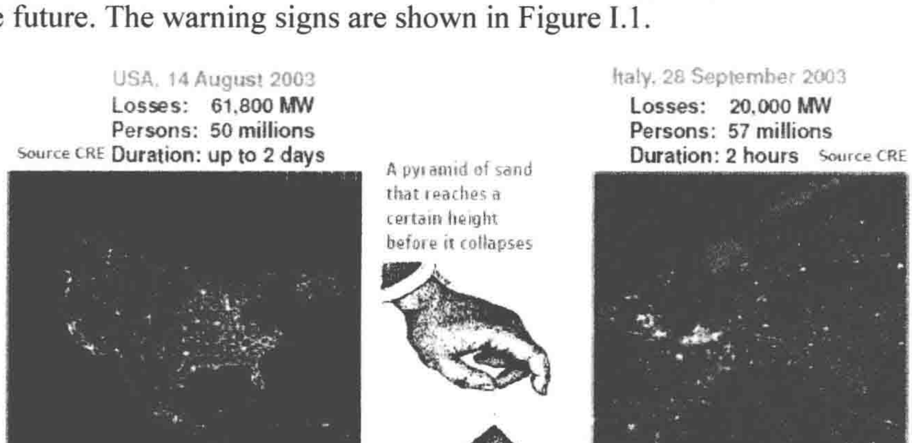

Figure I.1. *Blackouts in power networks*

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).

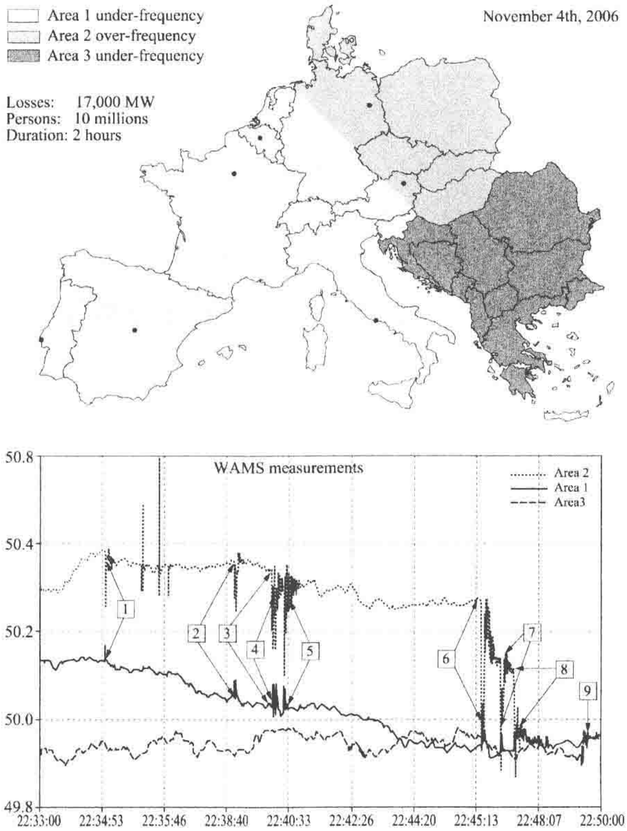

Figure I.2. *Blackout in Western Europe, 4th November 2006: frequency split and resynchronization process (source: ENTSOE)*

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.