

# Preface

*Nihil difficile volenti*

Two fundamental control functionalities are required for any electrical power system to operate:

- The equilibrium existing between the real power delivered by generators and that absorbed by loads and losses must be continuously maintained. This equilibrium, characterised by constant frequency of a system's AC variables, is achieved by controlling the generated active power in order to compensate for variations in load;
- Grid voltages must be maintained around nominal values with power transfer taking place at low current values (i.e., operation is carried out far below that which would cause line overload) and at low losses, guaranteeing safe and reliable operation of system components (far from over- or under-voltage, which would compromise the normal working of components). Voltage management is generally achieved by controlling the available on-field reactive powers as well as transformer tap positions through on-load tap changers.

According to this schematic subdivision, the two main controls of a power system are:

- Independent of each other:
  - Constant frequency is maintained as much as possible by controlling generated active powers;
  - High, constant voltage is maintained as much as possible by controlling the system reactive powers and transformer tap positions.
- Achievable in practice by clear control solutions:
  - Generator active powers have to be modified in real time to maintain an unchanged system frequency;
  - On-field reactive powers provided by compensating equipment and generators have to be modified in real time to maintain an unchanged proper voltage in the grid.

When we consider the complexity of a multivariable, nonlinear, real power system, the above-mentioned simplified subdivision of the two control functionalities

remains valid even if changes in active power also impact system voltages and, conversely, variations in voltage also change power transfer and, therefore, frequency. That notwithstanding, the main contribution to frequency change is still given by generated active powers, whereas the most relevant contribution to grid voltage change is still determined by reactive power flows.

Furthermore, the main objective of generated active power is satisfaction of load demands in accordance with contractual requirements. Any generator production required by a dispatcher for controlling system frequency is only a small amount of total power. Therefore, controlling the active power flow by changing system voltages is theoretically possible, but this method is not used for practical problems, in part because of the difficulty operators would encounter in changing grid system voltages to their correct values at any instant.

On the other hand, the main objective of system reactive power control is grid voltage sustenance. Controlling voltage by changing the active production of the generator is theoretically possible, but, again, this method is never used in practice except under extreme operating conditions where there are high system security risks.

Therefore, separating voltage control in a power system from aspects of generator speed and grid frequency control is fully justified: distinguishing between the two is not only technically possible (interactions that exist are easily managed by the main controls); it is also the common and practical way a power system operates.

This book provides a general overview and detailed descriptions of the principal voltage control aspects of a power system, distinguishing between continuously operating real-time, stabilising controls and discontinuous stepping controls, which are always ready to operate but which are active only when system voltage protection is needed. Moreover, among continuous solutions, the book distinguishes wide area transmission network control from distribution grid with renewable-energy generator control.

Introductory to an analysis of grid/wide area voltage is an in-depth survey of power system component voltage control solutions. In fact, generators, compensating equipment, power electronic equipment and transformers with on-load tap changers basically support grid voltages. Therefore, any proper analysis of multiple and overlapped grid voltage control loops asks for an all-inclusive view of the complexity of different but simultaneous control actions, as well as a deeper understanding of control functions and of each solution's performance. With this aim attention is given to:

- Differences that exist among available voltage control resources, their peculiarities and limits;
- Relevant aspects of each control system that aid an understanding of their functionalities and dynamic performance;
- Hierarchical differences among the control systems considered and coordination needed for each to realize its proper contribution;
- Benefits related to each control and the working conditions required for their achievement.

Only at the end of this thorough and complex preliminary analysis can we see clear evidence of the true benefits and limitations of the more traditional voltage control solutions and gain a better understanding and appreciation of the innovative grid voltage control and protection solutions proposed here. Such solutions aim to improve the security, efficiency and quality of electrical power system operation.

This is not a traditional academic book: it does not give a wide overview of the contributions of major experts to each considered topic, nor does it dedicate equal space to each. On the contrary, it mainly relates the author's experience and belief in each aspect's importance, its usefulness in practice and its effectiveness, giving more space to those contributions he deems most important. Other contributions are therefore mentioned when needed for comparison or to help readers see differences and/or to clear up possible misunderstanding or incorrect beliefs, some of which are widespread.

Moreover, the book does not dedicate much space to those aspects of voltage control and protection already widely addressed and gathered in classic books on power system control. The presentation of these basic topics is limited to their essential points, serving only as introductory. In keeping with this approach:

- References herein cannot cover exhaustively the available contributions to each topic; the papers most often cited are my own.
- The book is not for beginners but rather for those who are versed in electrical power systems and possess basic competencies in automatic control of dynamic/multivariable processes.

Finally, those basic competencies in electrical power systems which are assumed and therefore not assisted by the book include:

- Electrical technology and principles; electrical generators, electronic converters and electrical grids;
- Dynamic modelling of power systems in accordance with process physics, related automatic control objectives and applicable simplification of models to aid analysis/understanding of the results presented;
- Automatic control theory applied to dynamic processes and related design/analysis aspects.

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