1

Introduction

1.1 Introduction

A power system is one of the most complex systems that have been made by man. It is an interconnected system consisting of generation units, substations, transmission, distribution lines and loads (consumers). Additionally, these encompass a vast array of other equipment such as synchronous machines, power transformers, instrument transformers, capacitor banks, power electronic devices, induction motors and so on. In this context the smart grid has contributed even further to this complex situation, of which a better understanding is required. Given these conditions, signal processing is becoming an essential assessment tool to enable the engineer and researcher to understand, plan, design and operate the complex and smart electronic grid of the future.

Signal processing is used in many different applications and is becoming an important class of tools for electric power system analysis. This is partly due to a readily available vast arsenal of digital measurements that are needed for the understanding, correlation, diagnosis and development of key solutions to this complex context of smart grids.

Measurements retrieved from numerous locations can be used for data analysis and can be applied to a variety of issues such as:

- voltage control
- power quality and reliability
- power system and equipment diagnostics
- power system control
- power system protection.

This book focuses on electrical signals associated with power system analysis in terms of characterization and diagnostics, or where signal-processing techniques can be useful such as for the analysis of possible concerns about individual loads and/or state of the system.

A large variety of equipment can be used to capture and characterize system variations. These include monitors, digital fault recorders, digital relays, various power system controllers and other intelligent electronic devices (IEDs). Furthermore, power system conditions and events require signal processing techniques for the analysis of its recorded signals. This book

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promotes attentiveness to issues in the signal processing community. It will provide an overview of these techniques for the understanding and promotion of solutions to its concerns.

1.2 The Future Grid

The future of the developed, developing and emerging countries in a global economy will rely even more on the availability and transport of electrical energy. It is believed that in the near future the global consumption of electrical energy will grow to unprecedented levels. Additionally, security and sustainability have become major priorities both for industry and society.

The deployment of sustainable/renewable energy sources is crucial for a healthy relationship between man and his environment. These changes are driven by a number of developments in society, where the transition to a more sustainable society is a priority. Moreover, the availability of various new technologies and the deregulation of the electric industry may have an additional impact on future developments.

The sustainable and low-carbon imprinting of a society and problematical energy storage requires an integrated power grid which will play a central role in the achievement of energy-efficiency targets and savings. However, the large-scale incorporation of renewable energy production and novel forms of consumption will substantially increase the complexity of its electricity distribution system. The urgency requirement of this complex smart energy grid is evident from the extensive research and development in this area.

An overall picture of this new complex infrastructure is shown in Figure 1.1, where the smart grid of the future can be seen as a merging of the power system and control information technologies.

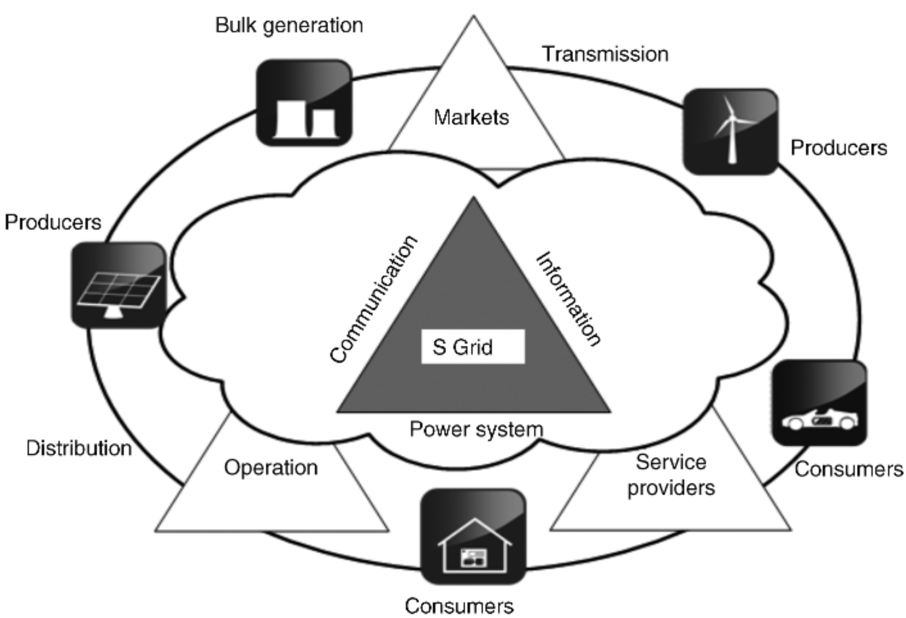

Figure 1.1 The grid of the future.

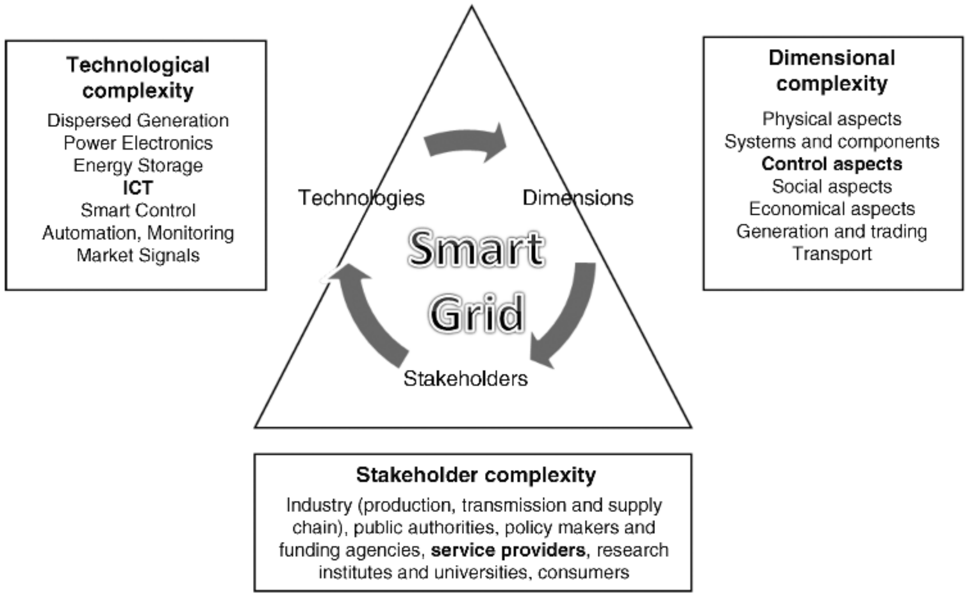

Figure 1.2 The complexity of the smart grid: technologies, stakeholders, dimensions.

The complexity of a smart grid (illustrated in Figure 1.2) might be classified as:

- dimensional complexity
- technological complexity
- stakeholder complexity.

The science and art of designing technological systems within a complex societal environment is a challenging job. In order to produce systems that are synchronized with all the different normative moments of each complexity, new projects must take into account the abovementioned evolving reality. In philosophical terms, a simultaneous realization of different laws and norms is required, where dimensional, technological and stakeholder issues with conflicting objectives and interests need to be accommodated in a well-integrated manner.

In this context, signal processing emerges as one of the most important and effective tools for investigating the operation of such a system.

1.3 Motivation and Objectives

In topics such as power quality, research has traditionally been motivated by the need to supply acceptable voltage quality to end-user loads where voltage, current and frequency deviations in the power system are normal concerns of a systems operator.

The characterization of the incompatibilities caused by these deviations requires an understanding of the phenomena themselves. Listed among the possible aspects to be investigated are the need for efficient representation of the voltage and current variations and the signal processing to understand how equipment behaves. There is also a need for continuous monitoring that can capture deviations, events and variations and the correlation with equipment performance, decomposition, modeling, parametric estimation and identification algorithms.

This book aims at utilizing more widely and effectively the signal processing tools for electrical power and energy engineering systems analysis. The text uses an integrated approach to the application of signal processing in power systems by means of the critical analysis of the methodologies recently developed or in innovative ways. The main techniques are critically illustrated, compared and applied to a variety of power systems signals.

Both traditional and advanced signal processing tools for monitoring and control of power systems are considered. To meet future requirements, methods and techniques shall be engaged to explore the full range of signals that derive from the complex interaction between suppliers, consumers and network operators. The book is not only intended to convey the theoretical concepts, but also to demonstrate the application.

How do engineers in the research and development of electrical grids cope with this increased complexity? It is impossible for an engineer to take the full complexity of these systems into account? During the design process, focus is generally on one or two aspects, one or two components or systems or the perspective of one or two parties involved. In other words, the complex system is reduced to a simplified, neatly arranged subsystem in order to design a new component, to study its performance and to optimize its stability. Through the years this has proven to be a very practical approach as long as the system does not experience major changes, allowing engineering judgment to be used in the simplification process. Unfortunately, a direct consequence of this is that it is not the whole system that is considered: only a reduced system.

In research and development, reduction is unavoidable. Engineers and researchers therefore have to be aware that they study and design in the context of reduced realities. As a consequence, they have to question themselves continuously whether they are missing any relevant dimensions. In practice, engineers cannot easily handle all the technical and non-technical dimensions of an electrical system due to the enormous complexity of smart grids and the requirements of all parties involved, including the requirements of governments and powerful stakeholders. As a consequence it is easy to miss relevant dimensions, to overlook important interactions between technical systems, to neglect the interests of certain parties and to lose a great amount of information. The interaction between multitudes of participants produces very complex signals that must be monitored and processed in order to determine the state of and developments around devices and systems, as depicted in Figure 1.3.

1.4 Signal Processing Framework

The condition of the grid can be fully assessed through the measurement and analysis of signals at different points in the system. Figure 1.4 illustrates the basic concept of signals and parameters that can be processed and derived in steps. First, three-phase signals are decomposed into time-varying harmonics and these are then processed by symmetrical components. The result provides the engineer with a unique tool to visualize the nature of time-varying imbalances and asymmetries in power systems.

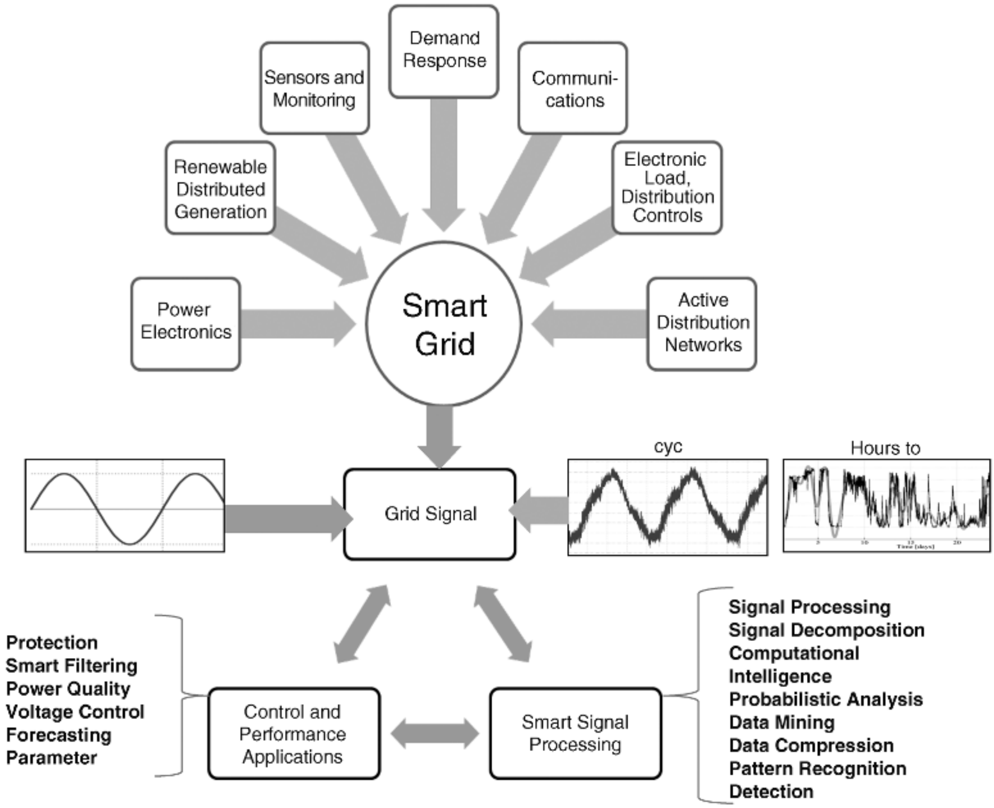

Figure 1.3 Signals, technologies and interactions.

Figure 1.5 further summarizes the signal processing that includes the measurement, monitoring and processing sequences from acquisition, analysis, detection, extraction and classification of the waveforms which might carry useful information for identification of system events, phenomena and load characteristics.

As new signal processing tools are developed to deal with the smart grid developments, it useful to remember that the development of signal processing began in the late 1970s. Figure 1.6 shows the progression of these developments starting with the Fourier series and progressing to time-frequency decompositions, analyzers and advanced signal processing for smart grids. Figure 1.7 shows a summary of these signal processing aspects in the context of smart girds, emphasizing applications, techniques and specifications.

In Figure 1.8 a comprehensive approach to the use of signal processing is illustrated. Here it can be seen that voltage and current signals at a specific point (even in a remote location) can be used to determine impedance, power factors, power flow, stability and so on, where such information can be used by the system operator for more efficient control of the electric grid.

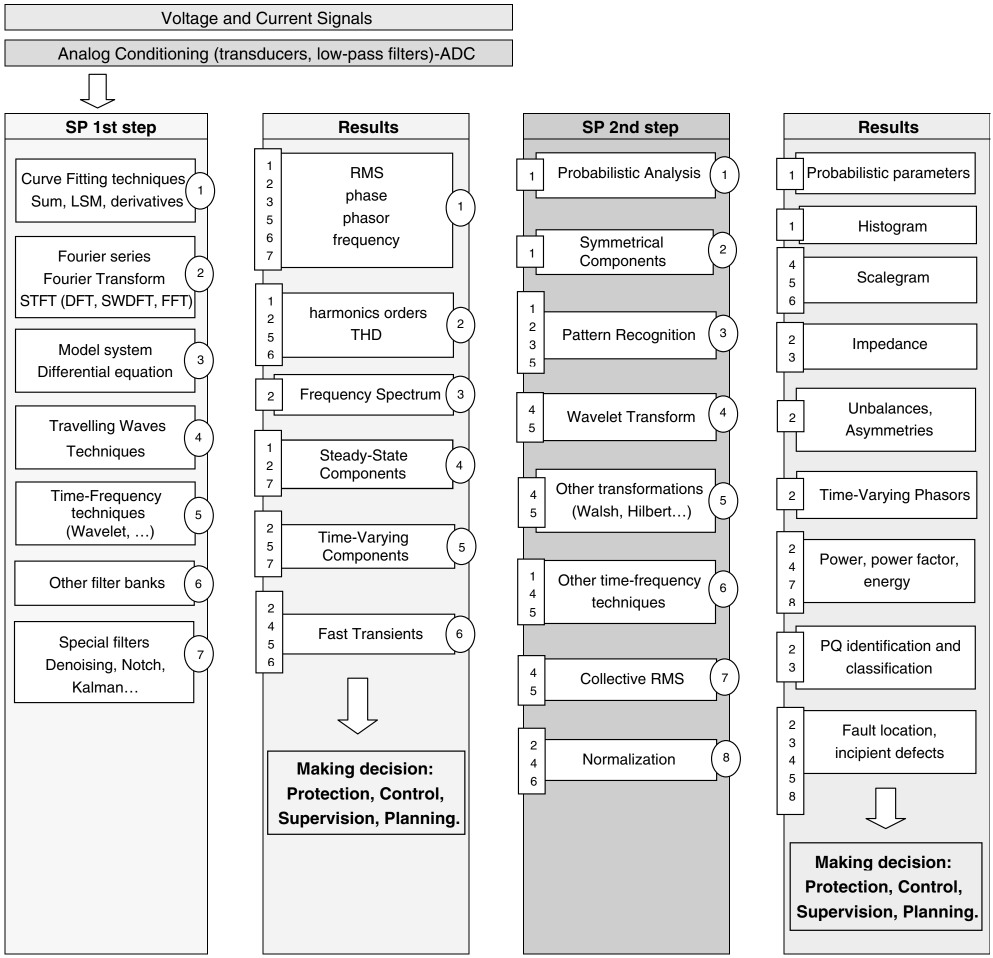

Figure 1.4 Basic concept of signals and parameters that can be processed and derived.

Finally, Figure 1.9 illustrates the perspective of a system, highlighting where signal processing can take place at different points within the network and providing crucial information to system operators.

Finally, the use of a phasor measurement unit (PMU), wide area networks (WANs), home area networks (HANs) and local area networks (LANs), together with developments in information and communications technology (ICT), can be integrated with power quality and energy measurements. Signal processing techniques can then be utilized to facilitate the control, protection and diagnosis of performance of the complex transmission and distribution of the micro cyber-physical smart grid of the future (see Figure 1.10).

Excellent literature has been published [1–7] describing the types of measurements and their technical specifications for power quality and other power systems operation performance requirements.

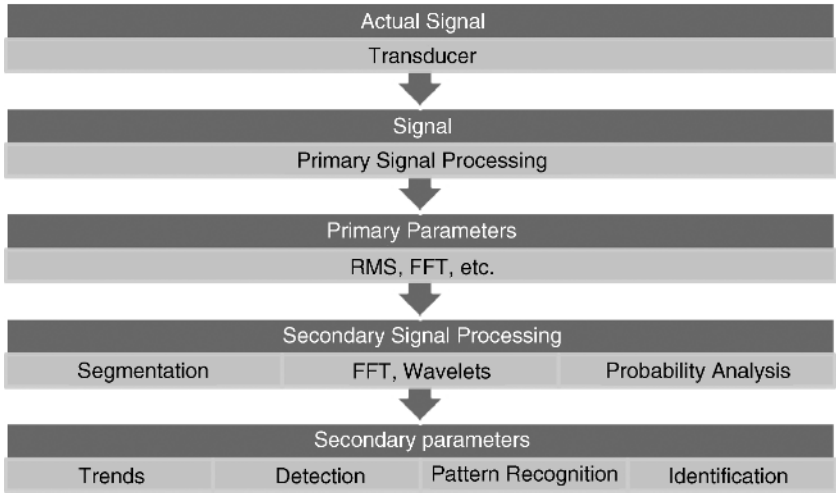

Figure 1.5 Measurement, monitoring and signal processing sequence.

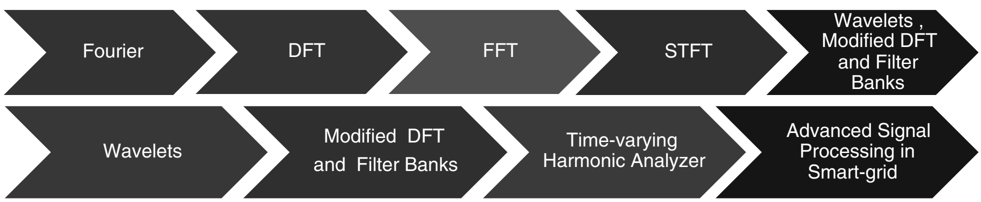

Figure 1.6 Summary of signal processing development.

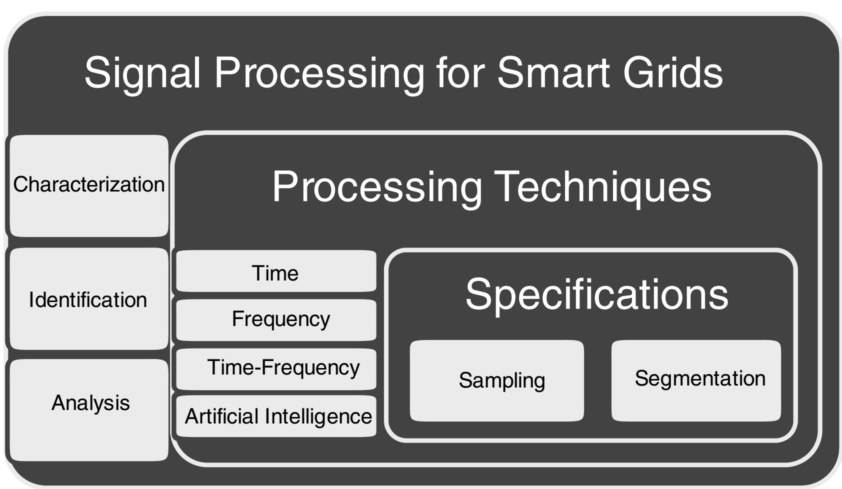

Figure 1.7 Signal processing techniques process.

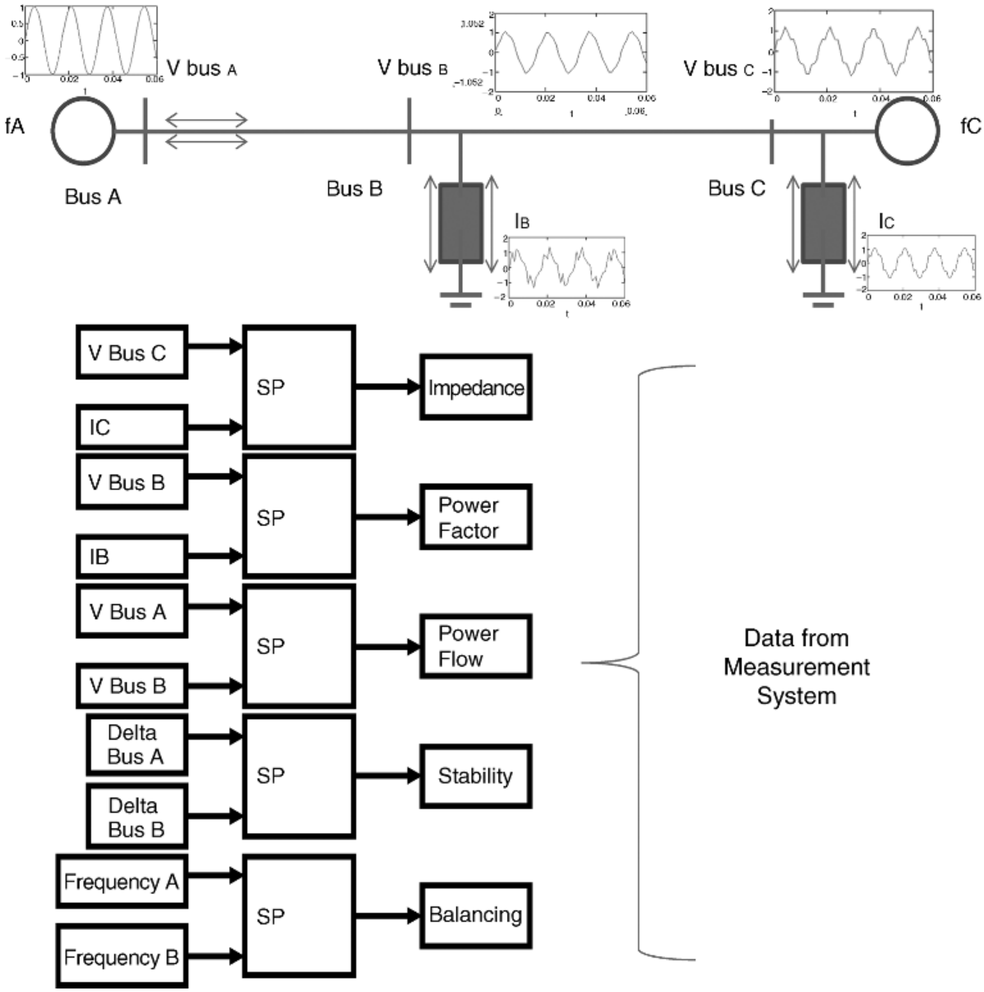

Figure 1.8 A comprehensive system-wide signal processing analysis.

1.5 Conclusions

A broad perspective of the material covered by the book is given in this chapter. We also expand on how to apply in an integrated fashion both traditional and advanced signal processing techniques for monitoring and control of power systems, particularly in the context of future complex smart grids. The methods and techniques explore the full range of signals that account for the interaction of a greater number of generation sources and active consumers with non-linear time-varying loads. The increased complexity of the electric grid, prompted by the development and implementation of smart grid technology and systems, requires a higher level of signal processing techniques. The authors hope this book will increase this awareness and assist with the visualization of solutions and applications.

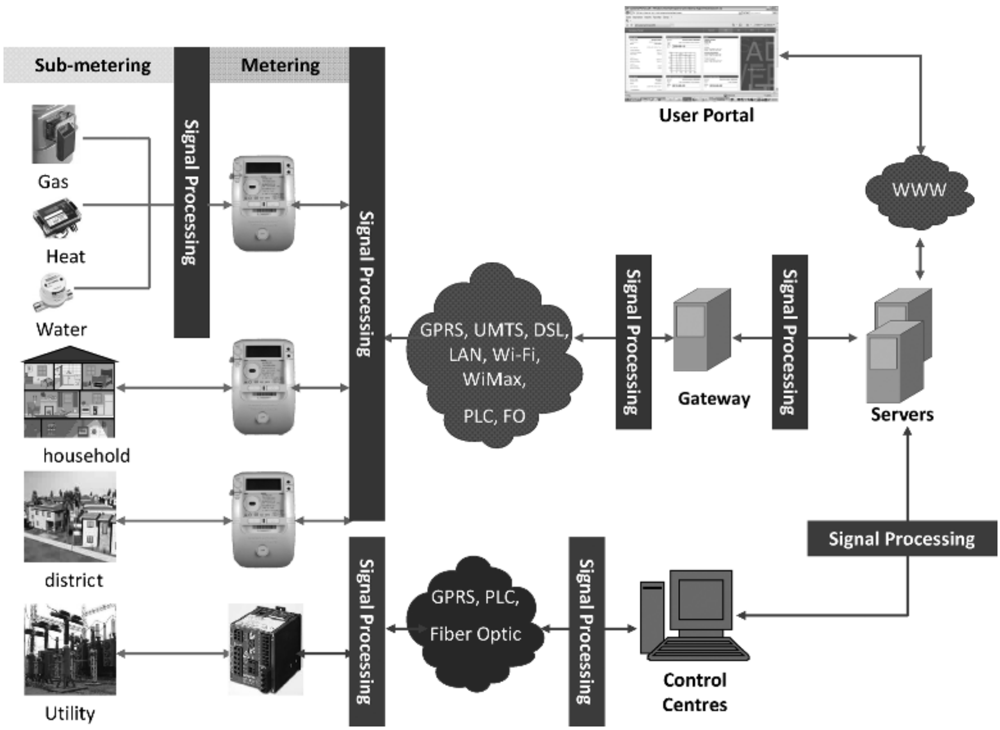

Figure 1.9 System perspective of signal processing.

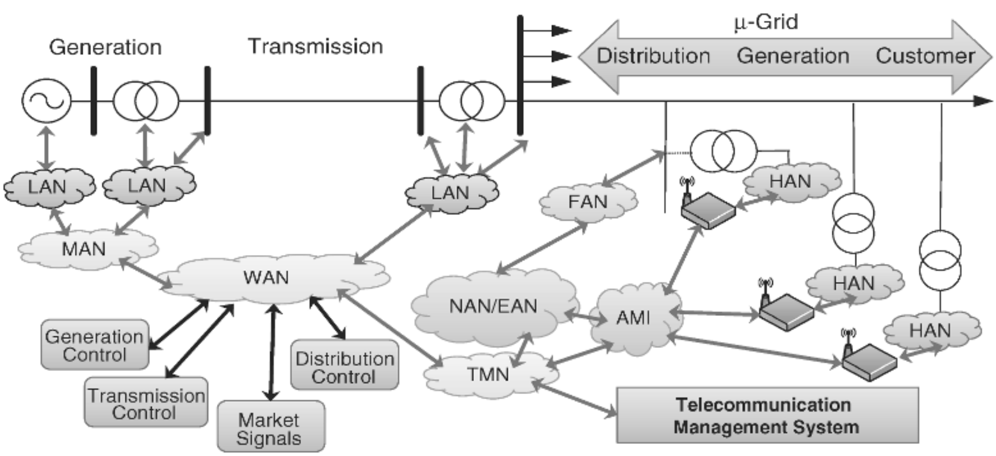

Figure 1.10 The complex transmission and distribution of the micro cyber-physical smart grid of the future.

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