CRITERIONS TO SELECT APPROPRIATE POWER DEFINITIONS EMPLOYED IN ACTIVE POWER DISTRIBUTION NETWORKS

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ABSTRACT

The main aim of our research activity is to deal with the issue of proposing selection criterions of power definitions to be employed in smart grids and active distribution networks. Distributed energy resources are connecting to the distribution grids. Moreover, there is a continuously increasing tendency to do demand side management via controllable loads. Almost all of the mentioned equipments are connected to grid and controlled through power electronics interfaces that proliferate considerably nonlinearity of the grid. In such a harmonic pollutant environment a set of generalized power definitions are required which can preserve their credibility and are able to compute power properties of the system. In this study, the concepts and key elements of smart grids and active networks are briefly described at first. Then, the problems and challenges regarding selection of power definitions are discussed. Afterwards, selection criterions of power definitions are proposed. Finally, a number of advanced power theories are assessed according to the proposed criterions.

INTRODUCTION

Progressing of the industrial countries and emerging various sensitive technologies increase the necessity of delivering reliable electric power with highest possible quality. Considering this situation has urged the transition of the power distribution systems from the conventional passive structure to the active and state of the art architectures. Distributed energy resources with various power capacity and ratings are connecting to the distribution grids. Moreover, there is a continuously increasing tendency to use plug-in electric vehicles (PHEV) with the capability of bidirectional energy transfer (V2G and G2V). PHEVs as well as lots of distributed generators and electric energy storages are connected to the grid through power electronics-based interfaces (PEI). The power flow regulation and the instantaneous power balance of the system should be adjusted via appropriate controlling of the PEIs.

With the aim of employing the most appropriate power definitions to control the abovementioned PEIs, it is the main purpose of this paper to assess the advanced power theories and extract the advantages and drawbacks of the theories. Proper selection of the definitions has a significant impact on the efficiency of the system, especially when the power quality-based ancillary services are planned to be provided. The practical power theories, taking into account the impact of imbalance and distortions on the definitions, should be evaluated to introduce the most suitable ones that are able to allocate instantaneously the precise and efficient capacities of active and reactive powers to be supplied by the PEIs. Besides, the performances of the theories in single-phase systems as well as poly-phase systems should be considered.

It is worthy to mention that the power definitions can be classified in two categories namely the energy-based definitions and the shape-based definitions. In the energy-based definitions energy and power of the signal is more important than its sinusoidal shape. On the other hand, in the shape-based definitions producing a pure sinusoidal signal has a grave importance. Impacts and results of employing the categories to control the PEIs are mentioned to make it clear that the selection should be done according to the connection objectives as well as the desired results. Moreover, considering the numerous and high number of dispersed sources and storages, it is essential to select definitions which are capable to coordinate them in order to supply efficiently the grid-side load demand and at the same time, to be commercially beneficial for their owners. Thus, the mentioned capabilities are analyzed and discussed to achieve some selection criterions of the power definitions.

The structure of this paper is organized as follow: at first the concepts and key elements of smart grids and active networks are briefly described. Then, the problems and challenges regarding selection of power definitions are discussed. Afterwards, selection criterions of power definitions are proposed. Finally, some of advanced power theories are assessed according to the proposed criterions.

SMART GRIDS

Although the current electricity infrastructure in most countries consists of bulk centrally located power plants connected to highly meshed transmission networks, a new trend is developing toward distributed energy generation, which means that energy conversion systems will be situated close to energy consumers and the few large units will be substituted by many smaller ones [1]. For the consumer the potential lower cost, higher service reliability, high power quality, increased energy efficiency, and energy independence are all reasons for the increasing interest in what is called “Smart Grids”.

Smart grid, as a necessary response to the environmental, social and political demands placed on energy supply, will

use revolutionary new technologies, products and services to create a strongly user-centric approach for all customers [2]. Smart grid is an intelligent, auto-balancing, self-monitoring power grid that accepts any source of fuel (coal, sun, wind) and transforms it into a consumer's end use (heat, light, warm water) with minimal human intervention [3].
As a vision, along with the abovementioned features, following cases have been attributed to smart grids:

- Flexibility: Fulfilling customers' needs whilst responding to the changes and challenges ahead
- Accessibility: Granting connection access to all network users, particularly for RES and high efficiency local generation with zero or low carbon emissions
- Reliability: Assuring and improving security and quality of supply, consistent with the demands of the digital age
- Being Economic: Providing best value through innovation, efficient energy management and 'level playing field' competition and regulation

To respond to the shift towards smart grids, a number of novel system concepts have been proposed. The two mentionable examples are active distribution networks and micro grids.

Active distribution networks

Active distribution networks: This concept has been proposed based on the need to adapt the passive distribution infrastructure to the myriad of novel distributed participants expected to appear in distribution systems [4]. Rapid changes in demand and generation, provision of network services by distributed participants, bi-directional energy flows, increased information exchange and intelligent appliances (demand side participation) will require controllable and scalable architectures. Concepts associated with active networks are virtual power plants, reattribution of control duties to network participants and solutions for dealing with information exchange among a very large number of participants.

Micro grids

Micro grids are generally defined as low and medium voltage networks with distributed resources, together with local storage devices and controllable loads [5]. They are small electrical distribution systems that connect multiple customers to multiple distributed sources of generation and storage. Micro grids have a total installed capacity in the range of a few kilowatts to one or two megawatts. The unique feature of them is that, although they operate mostly connected to the distribution network, they can be automatically disconnected to operate in islanding mode, in case of faults in the upstream network and can be resynchronized after restoration of the upstream network voltage. Within the main grid, a micro grid can be regarded as a controlled entity operated as a single aggregated load or generator and, given attractive remuneration, as a source of power or of ancillary services supporting the main network.

PROBLEM DEFINITION

There are significant technical challenges that have to be addressed in order to achieve smart grid and its coordinated control with the upstream conventional networks. As it is mentioned above, power electronics related devices have a critical and essential role in interfacing and controlling the future grids. Almost all of distributed generators, especially those which are associated with renewable energies, are connected and controlled through the PEIs. In fact, power electronics are integral components of renewable and distributed energy systems. Moreover, in the new environment, a great amount of electrical loads is composed by power electronic equipments, such as adjustable speed drives, controlled rectifiers, cyclo-converters, electronically ballasted lamps, arc and induction furnaces, and clusters of personal computers, represent major nonlinear and parametric loads which are potentially a host of disturbances for the utility and the end user [6].
In an smart grid intelligent power sources cooperate to meet the energy demand by exploiting renewable energy at the maximum extent [7]. The intermittency and variability of renewable generation whether wind, photo-voltaic or other technologies can create considerable effects on power system operation. This can impact quality of supply and security margins and consequently operational costs. This clearly necessitates comprehensive understanding and, in some situations integrated control, of both central and distributed generation and potentially of demand resources, at all voltage levels.
Accordingly, it is certainly critical to introduce a class of power definitions adapted to the new environment such that measurement algorithms and instrumentation can be designed which give guidance with respect to the quantities that should be measured or monitored for revenue purposes and engineering economic decisions. Actually, the definitions should be efficiently able to serve industry with the methods of identification and improvement of power properties of electric circuits as well as with precisely computing bidirectional flows of powers and energies within a restructured system with the aim of fulfilling a reliable electricity market.

SELECTION CRITERIONS OF POWER DEFINITIONS

With the aim of adopting appropriate and generalized power definitions to be employed in the new environment, a number of rational criterions are provided. From the practical viewpoint, a power theory should have the following characteristics:

- credible within both single phase and poly phase systems: remember that the future grids will be a dynamic market in which all single phase and three phase participants are able to energy exchange. Thus, it is necessary to employ unified power definitions through the grid which are credible within both single and poly phase (three phase) systems.

- understandable and practical: a reason that the instantaneous reactive power theory [8], although strongly objected, become popular in industry is that it is comprehensible and straightforward for implementing. On the other hand, a number of more complete power theories have not been so welcomed.

- requiring a minimum amount of memory: as the number of processing systems will be rapidly growing throughout a smart grid, it is technically as well as commercially efficient to devise theories with minimum amount of memory requirements for the same volume of computations.

- credible and efficient under imbalance and distortions: as long as an electric system is ideal that means all of the waveforms are sinusoidal and balanced, the definitions serve well. The main problems arise from the flow of nonactive energy caused by harmonic currents and voltages. Switching power converters, PEIs of distributed generators and electric vehicles and a vast variety of other power electronics equipments as the mandatory part of a smart grid proliferate considerably nonlinearity of the grid. In such a harmonic pollutant environment a set of power definitions are required which can preserve their credibility and are robustly able to compute power properties of the system.

- being able to evaluate electric energy quality: one of prime objectives of a smart grid is assuring and improving security and quality of supply. It is noticeable that quality disturbances originated from an electric load can deteriorate supply quality of neighbor loads. A smart grid is not only pollutant by harmonics but also pollutant by other aspects of power quality such as voltage sage, swell and notches. Employing appropriate power definitions, various quality controllers, at both sides of generators and loads, make necessary decisions regarding the assessed quality of electric energy.

- efficient in extracting the compensation reference waveforms: during last decade a considerable number of researchers have dealt with derivation of the compensation reference signals. Voltages and currents in systems with nonlinear loads can be asymmetrical, non-periodic, distorted and even unpredictable. Consequently, reference signals for the compensator control have to be generated in a situation where the power properties of the load are not well specified. Normally, the compensation objectives include harmonic suppression, reactive power compensation, voltage regulation and load balancing. Different power definitions have been applied to reach acceptable compensation goals; however, the primary results of compensations have usually been undesirable. That means the employed power definitions were unable to decompose accurately load currents. Flawless power definitions should be capable of extraction the precise compensation reference signals to be effectively employed in appropriate compensators. Actually, the definitions should be conservative with orthogonal power components.

- effective in detecting the sources of waveform distortion: responsibility and accountability should be completely regarded within an active distribution network. The selected power definitions should be capable to separate load and supply responsibility for reactive power, asymmetry and distortion [9]. Determination of the harmonic contributions between the customer and utility at the point of common coupling is necessary. Besides, the quantity and direction of power for each harmonic order should be set. The definitions should be able to set a basis for proper accounting of electrical supply.

- being able to do power decomposition: revenue metering is an extremely critical steps within an active distribution network. Accurate decomposition of power is necessary to attain the mentioned goal. In fact, the revenue can be calculated according to different parts of the net transmitted power. It is worthy to mention that within an active network all of the participants somehow deal with the electricity market where revenue metering has a grave importance.

AVAILABLE POWER THEORIES

Power definitions have been considered in electrical engineering since the invention of the alternative currents. However, a significant deal of effort has been put during last decades. Generally, the definitions can be classified in three categories, namely frequency-based, time-based and frequency-time-based methods. In addition, another classification is possible that power definitions can be divided as the energy-based definitions and the shape-based definitions. In the energy-based definitions energy and power of the signal is more important than its sinusoidal shape. On the other hand, in the shape-based definitions producing a pure sinusoidal signal has a grave importance. Various definitions are available now that can be employed in different manners; however definition of apparent power for unbalanced or non-sinusoidal three-phase power systems still remains a controversial issue at present.
In this section, a number of advanced power theories are briefly assessed regarding the proposed criterions:

- Budeanu's definitions [10]: it is one of a very first frequency-based power definitions. The definition is understandable and practical. Actually, it was the standard power definition for several years. Even at present, the definitions are applied in some countries. However, lots of critical points can be gathered against Budeanu's definitions. Having paid attention to the proposed criterions, Budeanu's definitions are not able to do power decomposition, computing the definitions require a considerable time and memory. Moreover, Budeanu's definitions cannot extract the compensation reference currents flawlessly.

- Instantaneous reactive power theory (The IRP method): a simple and straightforward time-based power definition. The IRP method is really popular in industry because it is a practical definition. However, it is not credible in single phase systems, loses the efficiency under imbalance and distortion, cannot determine the source of distortion, and is not able to do power decomposition accurately. In addition, its decompositions are not conservative.

- Emanuel's definitions [11]: these definitions are recommended by lots of experts and have an undeniable robustness. The last issue of standard power definitions released by IEEE is based on these definitions. Although Emanuel's definitions can support lots of mentioned criterions, the definitions are not efficient in extracting the compensation reference currents.

- Czarnecki's current physical component (CPC) concept [12]: maybe one can call it the most promising method to be employed in active networks. It is credible within both single phase and poly phase systems, credible under imbalance and distortion, able to evaluate electric energy quality, efficient in extracting the compensation reference waveforms and able to do power decomposition. However, it is not so practical. Besides, CPC requires a huge amount of memory and its calculations are time consuming.

In summary, one can say that there is not yet available a generalized power theory that can pass all of the proposed criterions.

CONCLUTION

The paper has dealt with the issue of proposing selection criterions of power definitions to be employed in smart grids and active distribution networks. The concepts and key elements of smart grids and active networks have been briefly described at first. Then, the problems and challenges regarding selection of power definitions have been discussed. Afterwards, selection criterions of power definitions have been proposed. Finally, a number of advanced power theories have been assessed according to the proposed criterions. It has been concluded that there is not yet available a generalized power theory that can pass all of the proposed criterions.

REFERENCES

[1] A. Mohd, E. Ortjohann, W. Sinsukthavorn, M. Lingemann, N. Hamsic, D. Morton, 2009, "Supervisory Control and Energy Management of an Inverter-based Modular Smart Grid", *IEEE/PES Power Systems Conference and Exposition, PSCE '09*, 1-6.

[2] European commission, 2006, "European Smart Grids Technology Platform Vision and Strategy for Europe's Electricity Networks of the Future", *EUR 22040*.

[3] X. Energy, 2007, "Xcel Energy Smart Grid: A White Paper," *Denver Business Journal.*

[4] P. Favre-Perrod, R. Critchley, E. Catz, M. Bazargan, 2009 , "New participants in SmartGrids and associated challenges in the transition towards the grid of the future", *IEEE Bucharest Power Tech Conference, Bucharest, Romania, 1-5.*

[5] European commission, 2007, "Strategic research agenda for europe's electricity networks of the future", *EUR 22580, ISBN 92-79-03727-7*

[6] J. L. Willems, 2010, "Budeanu's reactive power and related concepts revisited", *IEEE Trans. Instrument. And Measure., to be published.*

[7] H. K. Morales Paredes, A. Costabeber, P. Tenti, 2010, "Application of Conservative Power Theory to Cooperative Control of Distributed Compensators in Smart Grids", *Inter. school on nonsinusoidal currents compen., ISNCC'10, POLAND, 190 – 196.*

[8] Akagi H., Kanazawa Y., Nabae A., 1984, "Instantaneous reactive power compensators comprising switching devices without energy storage components", *IEEE Trans. Industrial Appl., IA-20, pp. 625-630.*

[9] A. Suzdalenko, A. Stepanov, I. Galkin, 2010, "Choice of power factor corrector for effective operation of MicroGrid and its elements", *Inter. school on nonsinusoidal currents compen., ISNCC'10, POLAND, 234 – 238.*

[10] C. I. Budeanu, 1927, "Puissances réactives et fictives". Bucharest, *Romania: Institut National Romain pour l'Étude de l'Aménagement et de l'Utilisation d'Énergie.*

[11] IEEE standard, 2010, "IEEE standard definitions for the measurement of electric power quantities under sinusoidal, nonsinusoidal, balanced, or unbalanced conditions", *IEEE Std 1459TM-2010*

[12] L. S. Czarnecki, 2008 , "Currents' physical components (CPC) concept: A fundamental of power theory", *Przeglad Elektrotechniczny (Elect. Rev.), vol. 84, no. 6, 28–37.*