Smart Grids: Importance of Power Quality

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Abstract. The transformation from a centralized electrical grid system to a distributed electrical system via smart grids has drawn tremendous attention. Smart grids introduce new technological concepts that require interconnection between sensitive electrical and electronics components. It is important to maintain electromagnetic compatibility between these components to assure uninterrupted and high quality supply of electricity in future under deregulated grid set-up. Realization of smart grids requires balance between two main trade-offs: efficiency and reliability. Often reliability is given priority however it is not always guaranteed. Power quality is one of the important aspects responsible for smart grids reliability and should not be neglected. An adequate power quality guarantees the necessary compatibility between all equipments connected to grids. Henceforth, in this paper presents a review on smart grids structure, significance and requirement of power quality, and different levels of power quality issues in smart grids.

Keywords: smart grids, power quality, levels of power quality, pricing, and energy internet.

1 Smart Grid: Opportunities and Vision

The review and research effort on smart grids and its aspect of power quality is based on current developments and well over 10 years of experience with CIMGE [1]. The Consortium for the Intelligent Management of the Electric Power Grid (CIMEG) was responsible for developing intelligent approaches to defend power systems against potential threats. CIMEG was led by Purdue University and included partners from The University of Tennessee, Fisk University, Tennessee Valley Authority, and ComEd (now Exelon) [1].

The importance of energy and its delivery infrastructure for humanity can never by overstated. The availability of resources (especially fossil fuels), determines that massive generation of energy, such as electricity, has been centralized. This has been the feature of the traditional electrical grid system and relies on important central power stations; thereby making difficult to integrate distributed energy sources and microgrid [2]. They most often only support one-way power flow and communication, i.e., from the utility to consumers. Further, utilities can barely track how energy is consumed across the grid and, as a consequence, have no possibility to provide any pricing incentive to balance power consumption over time. As utilities can only accommodate increases in demand up to a certain level, they are forced to rely on additional peak load

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power plants to cope with unexpected demand increases [3]. This is highly expensive and potentially polluting, particularly if plants use fossil fuels [4].

The above mentioned characteristics of a traditional electrical grid are its shortcomings. As a result, transformation from a centralized, producer controlled network to the one that is less centralized and more consumer-active has become imperative. The transformation that will promise [5]:

1. The change of industrys entire business model and
2. Its relationship with all stakeholders involving and affecting utilities, regulators, energy service providers, technology and automation vendor, and all consumer of electric power.

The vision of smart grids promises to make transformation in transmission, distribution, and conservation of energy possible by bringing philosophies and technological concepts that enabled internet to the utility and the electric grid. It employs digital technologies to improve transparency and to increase reliability as well as efficiency of electrical network. Tsoukalas et al. [6] showed that the progress made on smart grids has enabled novel and meaningful discussion on a full scale energy internet. The assumptions, the architecture, and the technical requirements essential for realization from smart grids to energy Internet is presented in [6]. Smart grids also provides/enables customers to react dynamically to changes in electricity prices. The implementation of such programs may reduce energy costs and increase reliability as shown in [7].

It is extremely difficult to present a unique definition of smart grids as the concept involve various components and concepts. Table 1 gives some of the selected definitions of smart grids. From Table 1, we realize that smart grid can be defined in two different ways: it is either defined from a solution prespective (“What are the main advantages of the grid?”) or from a components’ prespective (“Which components constiture the grid?”).

From a solution perspective, the smart grid is characterised by:

– **Intelligence** – capable of sensing overloads and rerouting power to prevent or minimize a potential outrage.
– **Efficient** – capable of meeting increased consumer demand without adding infrastructure.
– **Accommodating** – accepting energy from virtually any fuel source including solar and wind as easily and transparently as coal and natural gas; capable of integrating all better ideas and technologies - energy storage technologies.
– **Motivating** – enabling real-time communication between the consumer and utility so consumers can tailor their energy consumption based on individual preference like price.
– **Opportunistic** – creating new opportunities and markets by means of its ability to capitalize on plug and play innovation wherever and whenever appropriate.
– **Quality-focussed** – capable of delivering the power quality necessary - free of sags, spikes, disturbances, and interruption.
– **Resilient** – increasingly resistant to attack and natural disaster as it becomes decentralized and reinforced with smart grids security protocols.

Table 1. Selected Smart Grid Definitions

Organization/ Author	Grid / Concept	Definition
Climate Group [3]	Smart Grid	A “smart grid” is a set of software and hardware tools that enable generators to route power more efficiently, reducing the need for excess capacity and allowing two-way, real time information exchange with their customers for real time demand side management (DSM). It improves efficiency, energy monitoring and data capture across the power generation and Transmission & Distribution network.
Adam and Wintersteller [4]	Smart Grid	A smart grid would employ digital technology to optimize energy usage, better incorporate intermittent “green” sources of energy, and involve customers through smart metering.
Miller [8]	Smart Grid	The Smart Grid will: (i) Enable active participation by consumers; (ii) Accommodate all generation and storage options; (iii) Enable new products; services and markets; (iv) Provide power quality for the digital economy; (v) Optimize asset utilization and operate efficiently; (vi) Anticipate and respond to system disturbances (self-heal); (vii) Operate resiliently against attack and natural disaster.
Franz et al. [9]	eEnergy	Convergence of the electricity system with ICT technologies.
EPRI [10]	Intelli- Grid / Concept	The Intelli-Grid vision links electricity with communications and computer control to create a highly automated, responsive and resilient power delivery system.
DOE [11]	Grid 2030	Grid 2030 is a fully automated power delivery network that monitors and controls every customer and node, ensuring a two-way flow of electricity and information between the power plant and the appliance, and all points in between. Its distributed intelligence, coupled with broadband communications and automated control systems, enables real-time market transactions and seamless interfaces among people, buildings, industrial plants, generation facilities, and the electric networks.

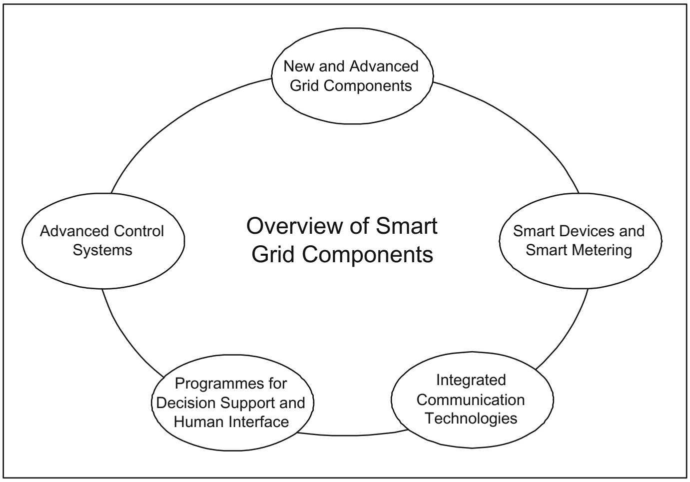

Fig. 1. Main component of a smart grid. Source: DOE, 2003, EPRI, 2006

From a technical components perspective, the smart grid is a highly complex combination and integration of multiple digital and non-digital technologies and systems. Figure 1 provides an overview of the main component of a smart grid: i) new and advanced grid components; ii) smart devices and smart metering; iii) integrated communication technologies; iv) programmes for decision support and human interfaces; and v) advanced control systems. These individual grid components do not need to be centralized, but can have more control stations and be more highly integrated.

In the ongoing discussion on smart grids, we observe that a complete realization of the smart grid presents several challenges. One of the several challenges that cannot be ignored is the need to ensure highest level of power quality. It is desirable to consider power quality not only from the electronic components usage in electrical network but also for the design of regulatory system for electrical networks. Therefore, this paper focuses on the satisfactory function of equipments for smart grid with respect to electromagnetic disturbances, i.e. power quality and types of power quality in the following sections.

2 Power Quality

Smart Grids results in drastic increase in the use of electronics in the power system. This requires satisfactory function of electrical and electronic equipments vital for realization of a robust smart grid structure. It opens up the opportunity for an evermore sophisticated electrical system containing lots of electronic devices both controlling the power flow itself, so called power electronics, and electronics controlling the power electronics and other devices.

Power quality is one of the important aspects of smart grid and should not be neglected. An adequate power quality guarantees the necessary compatibility between all equipment connected to the grid. It is therefore an important issue for the successful and efficient operation of existing as well as future grids. The “smart” properties of future grids poses challenges for new approaches to achieve efficient management of power quality. Especially the advanced communication technologies can establish new ways for selective power quality management. Power quality covers two groups of disturbances: variations and events [24]. While variations are continuously measured and evaluated, events occur in general unpredictable manner and require a trigger action to be measured. Important variations are: slow voltage changes, harmonics, flicker, and unbalance. Important events are rapid voltage changes, dips, swells and interruptions. The actual power quality (i.e. the disturbance levels) results from the interaction between the network and the connected equipments.

3 Power Quality Issues

Bollen et al. [13] discussed different types of power quality issues in smart grids which includes: (i) emission by new device; (ii) interference between devices and power-line communication; (iii) allocation of emission limits; (iv) improving voltage quality; (v) immunity of devices; and (vi) weakening of the transmission grid.

3.1 Emission by New Device

Smart grids introduces growth both in production at lower voltage levels (distributed generation) and in new types of consumption (for example, charging stations for electric vehicles, expanded high-speed railways, etc.). Some of these new types of consumption will emit power-quality disturbances [14, 15, 16, 17], for example harmonic emission of the lower odd integer harmonics (3, 5, 7, 9 etc).

3.2 Interference between Devices and Power Line Communication

Communication between devices, customers, distributed generators, and the grid operator is a salient feature of smart grid. Many types of communication channels are possible. Power-line communication might seem an obvious choice due to its easy availability, but choosing power-line communication could introduce new disturbances in the power system, resulting in a further reduction in power quality. Depending on the frequency chosen for power line communication, it may also result in radiated disturbances, possibly interfering with radio broadcasting and communication. It is also true that modern devices can interfere with power-line-communication, either by creating a high disturbance level at the frequency chosen for power-line communication, or by creating a low-impedance path, effectively shorting out the power-line communication signal [18].

3.3 Allocation of Emission Limits

In traditional grids, the number of existing customers and expected future customers to be connected to the grid is generally known. Thus, the total amount of acceptable voltage distortion is divided over all existing and future customers. As a result, for each new customer a so-called emission limit is allocated [19]. With smart grids, the amount of consumption will have no limit. This continued growth in both production and consumption could lead to the harmonic voltage distortion becoming unacceptably high. Also the number of switching actions will keep on increasing and might reach unacceptable values. As a result, the system strength is no longer determined by the maximum amount of consumption and/or production connected downstream, but by the total amount of harmonic emission coming from downstream equipment.

3.4 Improving Voltage Quality

One of the aims of smart grids is to improve the performance of the power system (or to prevent deterioration) without the need for large investments in lines, cables, transformers, etc. From a customer viewpoint, the improvements can be in terms of reliability, voltage quality or price. The only voltage-quality improvement expected to be made by smart grids in the near future would be a reduction in longer-term voltage-magnitude variations. In theory, both under-voltages and over-voltages might be mitigated by keeping the correct local balance between production and consumption [20, 21]. The same balance between "production" and "consumption" can in theory also be used for the control of harmonic voltages. Smart grid communication and control techniques, similar to those used to balance consumption and production (including market rules), could be set up to reduce harmonic emissions. This could solve the growing harmonic emission issue with growing amounts of production and consumption.

3.5 Immunity of Device

Simultaneous tripping of many distributed generators due to a voltage-quality disturbance (like a voltage dip) is the subject of active discussion [22, 23]. As smart grids attempts to maintain a balance between production and consumption, mass tripping of consumption could have similar adverse consequences.

3.6 Weakening of the Transmission Grid

The increased use of distributed generation and of large wind parks will result in a reduction of the amount of conventional generation connected to the transmission system. The fault level will consequently be reduced, and power-quality disturbances will spread further. This will worsen voltage dips, fast voltage fluctuations (flicker) and harmonics. The severity of this has been studied for voltage dips. The conclusion from the study is that even with 20% wind power there is no significant increase in the number of voltage dips due to faults in the transmission system [24].

4 Conclusion and Future Work

Smart grids can enable more renewable and efficient use of electricity. It is expected to boost an increased use of electronically based equipment in the electrical power system. Most of these electronic components are highly sensitive to electromagnetic disturbance. Replacement and maintenance of such components is an expensive affair. Hence it is important to maintain power quality level both in current and future grids. The issue of power quality at different levels and the challenges associated with each level were discussed. Thus new development requires new approaches and perspectives to address the issue of power quality in smart grids.

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