The Anti-Harmonic Ability and Power Quality Improvement of Smart Grids

Junqi Wu*

Department of automation, North China Electric Power University, Baoding 017003, China

*Corresponding author: wujunqi@ncepu.cn

Abstract. The purpose of this paper is to evaluate the influence of harmonic interference on power transmission in photovoltaic power plants, and to add harmonic filters in the transmission process to maintain the operating standard of the distribution system. Finally, the technology status of smart grid and its influence on power quality are discussed.

Keywords: Power quality, harmonic filter, smart grids.

1. Introduction

The normal operation of modern industry depends on power quality, because the interruption of distribution system can significantly affect the performance of electrical equipment. The power quality problem is a practical problem, which takes into account the diversity of equipment and various risks of deviation from normal operation state. When a power system operates, the frequency varies with the power, and it is impossible to maintain the nominal voltage of all nodes, nor the ideal sinusoidal waveform of voltage or current. The degradation of quality parameters of distribution system is inevitable. But the level must be within the acceptable range of current standards. Therefore, it is necessary to identify the interference, evaluate it and control it [1].

The first part of this paper introduces the current situation of smart grid technology. Taking wind power generation system as an example, the influence of harmonic interference on electric power transmission is evaluated from different angles, and the methods to solve these technical problems and their influence on total voltage harmonic distortion are proposed. The second part analyzes the prospect of smart power grid from the perspective of power quality, and forecasts the future of power system and power grid.

2. Smart grids

2.1. An overview of smart grids

Smart grid technology is a set of control system and network management, sensors and communication information facilities integrated, with both traditional elements and cutting-edge technologies. The technology could modernize, rather than replace, existing power grids to meet the needs of today's society and provide users with real-time information that enables them to make informed choices. Smart grids can use digital technology to provide power or integrate renewable resources. In addition, users
can reduce consumption in maximum time by adjusting the amount of electricity extracted from network
demand.

Photovoltaic power generation system adopts modular structure: photovoltaic generator, energy
conversion system, battery and safety elements (as shown in Figure 1). It is realized by coupling the
generator with the controller, which is used to adjust the charging mode of the battery.

![Diagram of PV system](image)

**Fig. 1 Structure of the PV system**

### 2.2. Evaluation of power quality
Since the distribution system is designed according to sinusoidal waveform, the evaluation of current
and voltage distortion waveform is of special significance. Deviation from sinusoidal form will cause
damage to users and reduce the overall performance of distribution operators. Power quality refers to a
set of indexes of continuous power supply under normal operating conditions of voltage and frequency.
Harmonics distortion are disturbances with multiple integers of frequency caused by any device or
nonlinear load \[2\]. Nonlinear passive devices generate odd harmonics and the active devices generate
the even harmonics. In the network we could have non harmonic components: under harmonics or inter-
harmonics generated by the frequency converters or asynchronous engines that use sliding phenomenon.

Connecting the non-linear loads in the distribution network will lead to undesirable effects on power.
The wind and PV plants who have a variable power generation will produce important distortions at
point of common coupling.

The power quality impact of PV plants and harmonic filters connected to the distribution system can
be assessed by means of the THD indicator. Total harmonic distortions are measured as a percentage of
standard frequency. THD indicator can be expressed as:

\[
THD = \sqrt{\frac{\sum_{h=2}^{\infty} U_h^2}{U_1}}
\]

Where \(U_h\) is harmonic voltage and \(U_1\) is the fundamental component of voltage. For practical cases,
the total demand distortion indicator (TDD) is used. Expressing the current harmonic level based on the
maximum circuit current delivers more accurate current distortion effect on the supply buses voltage. TDD indicator can be expressed as:

\[ TDD = \sqrt{\frac{\sum_{h=2}^{H} I_h^2}{I_L}} \]  

(2)

2.3. Power quality improvement devices of smart grids

In order to improve the reliability, safety and efficiency of the power system, a special filter device is used [3]. Filters are used to limit the total harmonic distortion of the grid. In order to limit the harmonic level of current and voltage waveform, active filter (with time domain correction), passive filter (with frequency domain correction) and hybrid filter are used.

![Passive filters](image)

Fig. 2 Passive filters

The most common filter is the passive filter, shown in Figure 2, which is used to reduce voltage and current waveform distortions generated by power system elements (capacitors or inductors). Passive filters are connected to the substation bus of the wave-dividing equipment to limit the level of harmonics in the power supply system.

The dimensions of passive filters are related to the specific information of power grid, power harmonic and total harmonic distortion coefficient. Placing these filters near jamming devices is a more expensive solution, but it can reduce grid losses.

3. Case study and simulation

When the distribution system is developing towards smart grid, this case focuses on the analysis of PQ problems caused by photovoltaic power stations and household appliances, and how to solve this problem with passive filters.

3.1. Model building

In this case, the PQ problem we are discussing is the harmonic disturbance caused by load changes of photovoltaic power stations and household appliances. In order to evaluate harmonic interference, we designed a smart grid topology.
The first step in this study is to evaluate the harmonic distortion of the three systems without requiring any technical solutions to mitigate the distortion. After harmonic power flow simulation, the results are shown in Table 1, where THD values of important nodes are given [4].

| Electrical appliances | U [kV] | THD [%] |
|-----------------------|--------|---------|
| 1                     | 0.6    | 23.48   |
| 2                     | 0.6    | 13.66   |
| 3                     | 0.6    | 14.28   |

3.2. Regulation of harmonic filters
The second step of the simulation is to solve the problem caused by the interfering load [5]. The solution is to connect a passive filter with a second order damped model in each system.

The root cause of harmonic generation is due to nonlinear load. When the current flows through the load, it does not have a linear relationship with the applied voltage, and a non-sinusoidal current is formed, thus generating harmonics. Harmonic frequency is an integral multiple of fundamental frequency. According to the analysis principle of French mathematician M. Fourier, any repeated waveform can be decomposed into sine wave components containing fundamental frequency and a series of harmonic multiples of fundamental wave. Harmonics are sine waves, and each harmonic has a different frequency, amplitude, and phase angle. Harmonics can be divided into even and odd order, the third, fifth and seventh serial odd harmonics, while the second, fourth, sixth and eighth are even harmonics. For example, if the fundamental wave is 50Hz, the second harmonic is 100Hz, and the third harmonic is 150Hz.

The harmonic component transmitted in the power network is mainly the second harmonic, and the distortion of power quality is also mainly caused by it. So, we add a second order harmonic filter, as is shown in Fig. 4. Harmonic flow simulation as shown in figure 8, THD calculation results as shown in Table 2.
Fig. 4 Schematic diagram of second order harmonic filter

Table. 2 THD for smart grids with passive filters

| Electrical appliances | U [kV] | THD [%] |
|-----------------------|-------|---------|
| 1                     | 0.6   | 9.63    |
| 2                     | 0.6   | 4.69    |
| 3                     | 0.6   | 5.74    |

In Table 2 we see the impact of the filters because the THD values have a strong decrease after the connection of the filters.

The data without harmonic filter and the data with harmonic filter are represented by oscilloscope, as shown in Fig. 5. The upper part is the output waveform with second-order harmonic filter added, while the lower part is the original output waveform.

Fig. 5 Contrast of output waveform

Analysis of the above results, new connection in the power grid harmonic filter, can effectively reduce the distortion index, namely power quality is improved significantly, therefore, can draw the following conclusion: according to the electrical connection in the different structure, choose a different order of harmonic filter, to some extent, can solve the problem of power quality is low, maintain the normal operation of the power distribution system.
4. Predictive future grid model from smart grids

4.1. Smart grids
Smart grids are designed to improve overall performance, ensure the security of end users and grid operators, ensure the reliability of power systems, and allow the optimal use of centralized generation and storage, transmission, distribution, distributed generation, and user terminals.

Clearly, to build, operate and develop smart grids, three areas must ensure full integration [6]: the power sector, information systems and communications; Smart grid components include distributed generation, smart metering, automated grid management, and active demand management.

Basic applications of any smart grid include optimizing grid control and monitoring, user contribution to grid management, and increasing the physical capacity and flexibility of the network.

The smart grid concept stems from three technologies; Distributed generation, energy storage and demand side management. These technologies are classified as distributed energy [7].

4.2. Microgrids
A microgrid is a discrete energy power system consisting of distributed energy sources and dispersed loads. The basic purpose of microgrids is to ensure local, reliable, and affordable energy security for all residential communities, while also providing solutions for industrial and commercial consumers.

Although the main objective of microgrids is self-supply and operating independently on the distribution grid, maybe there will be some economic opportunities for microgrids to be capable of operating in parallel with the main power grid.

In many descriptions, microgrids are smaller versions of the conventional power grid. Like current electrical grids, they consist of power generation, distribution, and controls such as voltage regulation and switch gears.

However, microgrids differ from conventional electrical grids by providing nearer vicinity between power generation and power use, resulting in efficiency increases and transmission reductions. Microgrids also integrate with renewable energy sources such as solar, wind power, small hydro, geothermal, waste-to-energy, and combined heat and power systems. Microgrids perform dynamic control over energy sources, enabling autonomous and automatic selfhealing operations.

During normal or peak usage, or at times of the primary power grid failure, a microgrid can operate independently of the larger grid and isolate its generation nodes and power loads from disturbance without affecting the larger grid's integrity. Microgrids deal with existing power systems, information systems, and network infrastructure, and are capable of feeding power back to the larger grid during times of grid failure or power outages.

4.3. Digital power networks
As mentioned in the above section, for more than a century, conventional interconnected power systems, depends on continuity of service provided through the large number of generating power plants connected to network and injecting all of its output to that network, while a huge number of demands connected to the same network and consume what they require irrespective the amount or time of service.

Digital power networks, is a new energy-on-demand approach to power grids. This approach uses the demandsupply management model. Simply, users issue a request for the amount of energy in demand at a certain time, and the service provider must confer the request and allocates energy to the selected users at this time.

In this approach, the transmitted energy is delivered as detached quantities or energy packets. The difference in energy transmission between conventional power systems and digital power networks like the difference between analog and digital communication systems, analog and digital computers … etc., i.e., it is like the difference between any analog and digital system.

Because energy requests are very well known before, and with the aid of network operational optimization techniques and queuing theory, the system provider can and must isolate and deliver the
energy request packets on time over the shortest path till the consumer's terminals (user's address) without any instability pocket.

4.4. Virtual power plants

Virtual power plant is defined as an autonomous freelance micro-grid, or defined as a pool of different type of distributed generation resources which may be dispersed in different points of medium voltage distribution network, or may be defined as a network of decentralized medium-scale power generating units.

The interconnected generating units are sent through the central control room of the virtual power plant irrespective the operation or who is own. The main purpose of virtual power plants is to eliminate the loads connected directly to the grid by smartly distributed generated power by the individual units during periods of peak load. Virtual power plants, along with centralized control stations, can make a type of smart grid or can connect to existing smart grids.

Hence, and due to the principles of deregulation that started from the 21st century beginnings, digital power networks, is started to take a place in our life as a new energy-on-demand approach to power grids [8]. To serve the approaches of digital power networks, the transactive energy concept takes place for the proper operation of these digital networks. The formation of the five terminologies and technologies: distributed generation, smart grids, microgrids, digital power networks, and transactive energy concept, will lead to the future type of power plants; the virtual power plants, as shown in Fig.6.

![Fig. 6 Future of electric power systems](image)

5. Conclusions

The normal operation of modern industry depends on power quality, which can be improved by smart grid through a series of detection and control. In the case of smart power grid established in this paper, the harmonics are firstly identified, their risks are evaluated, and finally harmonic filters are applied to control. Smart grid has infinite potential in the future. The future of smart grid is analyzed, and the future of power system is forecasted.
References

[1] Shehzad Ashraf Chaudhry. Correcting “PALK: Password-based anonymous lightweight key agreement framework for smart grid”[J]. International Journal of Electrical Power and Energy Systems, 2021, 125.

[2] Viswanath Gajula, Rajathy R. An explorative optimization algorithm for sparse scheduling in-home energy management with smart grid [J]. Circuit World, 2020, 46(4).

[3] QUALCOMM Incorporated; Patent Issued for Harmonic Rejection Filter With Transimpedance Amplifiers (USPTO 10,778,188) [J]. Journal of Engineering, 2020.

[4] Ponraj Palanichamy, Arul Daniel Samuel, Venkatakirthiga Murali. Descriptive statistical approach for the assessment of the output of a virtual power plant in a secondary distribution network [J]. IET Generation, Transmission & Distribution, 2020, 14(11).

[5] Wang Guotao. A brief analysis of power system harmonic hazards and control measures [J]. Measurement and testing technology, 2019, 46(09): 73-74+78.

[6] Wang Chengshan, Li Peng. Development and Challenges of distributed power generation, microgrid and intelligent Distribution Network [J]. Power system automation, 2010, 34(02): 10-14+23.

[7] Chen Shuyong, Song Shufang, Li Lanxin, Shen Jie. Overview of smart grid technology [J]. Grid technology, 2009, 33(08): 1-7.

[8] S. Vergura, G. Siracusano, M. Carpentieri, G. Finocchio. A Nonlinear and Non-Stationary Signal Analysis for Accurate Power Quality Monitoring in Smart Grids [P]. 3rd Renewable Power Generation Conference (RPG 2014), 2014.