Wind Power Generation-Related Power Quality Issues

LU Yan

***Abstract*—As a promising renewable alternative, the wind power is highly expected to contribute a significant part of generation in power systems in the future, but this also bring new integration related power quality issues, which mainly consist of power flow fluctuation analyzed with current, voltage fluctuation and flicker severity factor (P_{lt} and P_{st}) as '*case study*', by its comparatively new characteristics, due to the fluctuation nature of the wind (velocity) and the comparatively new type of its generators (currently popular type of squirrel-cage induction). One practical solution to mitigate the wind generation integration related power quality issues is introduced in this paper, by using Energy Storage System (ESS).**

***Index Terms*—wind power, wind turbine generator (WTG), power quality, power fluctuation, energy storage system (ESS)**

I. Introduction

The consumption of electricity keeps growing on a worldwide basis, while most countries have set targets to reduce the emission of carbon dioxide or other air, water or soil pollution, which are caused by conventional fossil-fuel's combustion, in order to stop the Earth from warming up further. The widely accepted opinion is that these targets can only be met on one hand by energy-saving incentives and on the other hand by the large scale application of renewable energy [1].

The wind power generation is increasing considered as promising alternative from the aspect of the potential economy in the area with appropriate wind speed other than renewable energy' essential advantages [5]. Whereas, because of the wind power generation has its own characteristics which are different from the existing generating unit such as the fluctuation nature of the wind and the comparatively new types of its generators, connection of wind generators to power system could lead to many disturbances, such as: voltage fluctuations, flickers, harmonics, instability, blind power regulation problems, and transients [3]. These challenges regarding the network integration of wind power mainly consists of keeping an acceptable voltage level, and the power balance of the system, which should comply with fundamental standard reference [6]. Power quality issues connected with wind generation are not only important because of technical aspects, they are also vital on the free energy market.

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To study these integration issues of wind power, this paper starts from general introduction to wind power to analyze wind velocity's influence to wind power. Meanwhile, currently popular generator, which has a squirrel-cage induction machine, is discussed concerned of its impact on power quality indices. In succession, brief presentation of power quality will be covered, and quality parameters' characteristics of supply voltage with wind farms will be concluded from reference [7].

According to the study of reference [5], we will learn a practical solution to mitigate negative impacts of wind power related power quality issues especially with high various penetration levels.

II. Wind power and its generator

Mass in air flowing carries a certain amount of energy, which varies in proportion to the product of the air mass and the square of the velocity [1], as equation (1).

$$P = C_p * 1/2 * \rho * A * V^3 \tag{1}$$

Where:

P: power (Nm/s or Watt)

C_p: mechanical power coefficient (at slow shaft)

ρ : density of air (kg/m3)

A: rotor surface area (m2)

V: wind velocity (m/s)

Not all the energy present in the wind can be converted into usable energy at the rotor shaft. Using physical calculations it can be proven that the theoretical maximum efficiency of wind power is limited at about 59. So, the net electrical power output of a turbine can be determined when mechanical and electrical performance rates are also taken into account, as equation (2):

$$P_{elec} = C_e * 1/2 * \rho * A * V^3 \tag{2}$$

Where:

C_e: electrical efficiency rate (%)

Today, large modern turbines are able to achieve a total net efficiency Ce of 42 to 46% with respect to the energy of the undisturbed wind in a circular tube with a cross-sectional area equal to the gross rotor area.

Towards equation (2), we can find wind velocity's apparent influence to wind power, i.e. a disadvantage of wind power is the unpredictability of wind. Storm fronts in particular can cause a sudden increase in the wind power; furthermore, periods of low wind give little wind power.

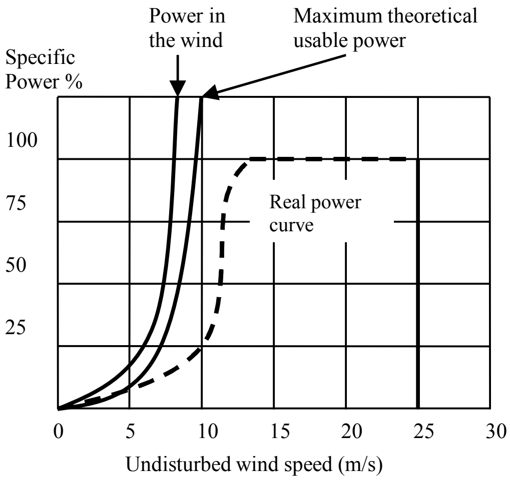

Figure 1. Power output in relation to wind speed

From Fig. 1, we can conclude that most wind turbines reach maximum power, also called the rated or nominal power, at wind speeds between 12 and 14 m/s [1]. At higher wind speeds, the power has to be kept constant in order not to overload the wind turbine structure or the electrical connection. For instance, at wind speeds over 25 m/s in Fig. 1, wind turbines were designed to shut down in a controlled way.

Another wind power generation's characteristic is its comparatively new types of generators. Reference [3] outlines three main wind generators structures:

1. The simplest and previously popular is the squirrel-cage induction generator connected directly to the grid, which has a fixed pitch of turbine blades generally.
2. Second is the doubly-fed induction generator. The stator winding of this generator is coupled with the system grid, and the rotor winding is connected to a voltage-source converter. This generator operates in wide spectrum of wind speeds and has lower impact on the grid, but the investment costs are higher.
3. Third structure has a synchronous machine, which can be operated in wide wind change range, and active and reactive power and voltage can be controlled. Moreover, this type requires a back-to-back converter for the grid connection to realize a double feed induction.

The first type of above generators cannot perform voltage control and absorbs reactive power from the grid. Phase compensating capacitors are usually directly connected [1] [3]. Although it is cheap and robust and therefore popular, the squirrel-cage induction generator has some defects from the system analysis point of view.

An important disadvantage is that during the switching of the phase compensating capacitors, transients occur, which can induce damages to sensitive apparatus, protection relays and insulation [2] [3] [6]. Furthermore, the impact on power quality indices cannot be ignored. Transient overvoltages and high current will exceed limitations to cause supplying interruption.

III. Power Quality

A. Introduction to power quality

What do we mean by 'power quality'? A perfect power supply would be one that is always available, always within voltage and frequency tolerances, and has a pure noise-free sinusoidal wave shape. Just how much deviation from perfection can be tolerated depends on the user's application, the type of equipment installed and his view of his requirements [2].

Table. I assembles power quality defects, which are the deviations from perfection, fall into five categories and their main possible causes.

From Table I, we can realize the real question concerned of power quality is compatibility between the equipment and the supply [2] [6]. Consequently, ensuring good power quality requires good initial design, effective correction equipment, co-operation with the supplier, frequent monitoring and good maintenance. In other words, it requires a holistic approach and a good understanding of the principles and practice of power quality improvement.

Especially, for wind turbine generator systems, there are some international standard available that characterizing the power quality of a grid connected wind turbine, as reference [6]. Similarly, reference [7] can be taken account of to measuring voltage fluctuation's limitation concerned of wind power generation.

B. Case study

Reference [4] presents the practical measuring results of parameters characterizing power quality for a medium voltage network to which over ten wind turbines were connected, in particular voltage fluctuations in the distribution network are in operation.

The scheme of the analyzed network is shown in Fig.2, whose power quality parameters were recorded in two different periods, and its main purposes are following: power quality measurements at connection points of wind turbines and at a feed point (GPZ), and the quality assessment of existing supply conditions from a standpoint of quality requirements

TABLE I

Power quality defects and their main possible cause

Type	Power quality defects	Main possible cause
1	Harmonic distortion	Arising within the customer's own installation and may or may not propagate onto the network
2	Blackouts	Caused by the supplier but can also by the failure of on-site equipment, conductors and connections
3	Under or over voltage	Caused by fluctuation of the supply voltage, typically due to the use of large fluctuating loads (flicker)
4	Dips (or sags) and surges	The responsibility of the supplier due to harmonic current
5	Transients	Switching or lightning strikes on the network and switching of reactive loads on the consumer's site or on the same circuit

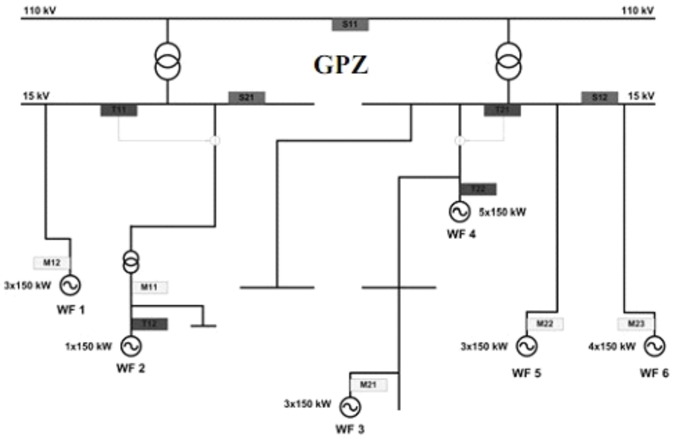

Figure 2. Scheme of analyzed medium voltage network

The effect of considered wind farms was calculated using the procedure described in reference [6].

According to the assessment of power quality, several important and effective statements were pointed out during the measurements, which are listed below:

1. From comparison with minimum and maximum values' changes of phase voltages, and maximum of phase currents of wind turbines, it is easily noticed that voltage dips and swells recorded at different measuring positions occur at the same time. However, disturbance, which resulted in the noticed voltage dips and swells, occurred outside the analyzed area of network.
2. From analysis of maximum values of current in relation to minimum and maximum values of voltages, and Long Term Flicker Severity Factor (P_{lt}) for wind farm, it is easily noticed that large values of factors characterizing voltage fluctuations are caused by voltage changes and are not correlated with current changes.
3. From analysis of correlation of phase current and short term flicker severity factor (P_{st}), measured results confirm that wind farms have no effect on a voltage fluctuation level in the analyzed network.
4. From the measured result concerned of the phase current of a wind power plant and P_{lt}, which shows that periods of small values of the P_{lt} at a large current and periods of large values of the P_{lt} at a small current, it was decided, in accordance with reference [6], to exclude the measured values of voltage fluctuation indices recorded during voltage dips/swells.
5. From analysis of numbers of eliminated values of P_{lt}, it was concluded that the events identified at various measuring positions were not connected with a limited area but with the whole analyzed network.
6. From comparison the value of P_{lt} measured with the one calculated with reference [6], noticed difference was appeared. Therefore, in calculation it must be taken into account that resulting values are only an additional component of disturbances and should be added to the existing disturbance level in the analyzed network.

Where:
GPZ: the feed point between wind turbine and supply grid
WF1~6: windmills
Analyzing instruments: TOPAS 1000 (symbol Tx in Fig. 1), MEMOBOX (symbol Mx in Fig.1), and SIEMENS OSCILOSTORE (symbol Sx in Fig. 1)

IV. Mittigation of the Wind Generation Related Power Quality

In fact, the most important hitch of Wind Turbine Generator (WTG) comparing with the fossil-fuel generating units is the irregular stream of electricity caused by the unpredictable wind variations. Especially when the wind power supplies a significant part of the load in the power systems, its intermittence can affect various aspects of power systems, and bring integration related power quality issues.

To study these integrations, reference [5] introduces a possible solution for mitigation by the application of Energy Storage System (ESS). The ESS with fast output power control is expected to suppress the wind power fluctuation, improve the power system stability, and counteract to the disturbance on the grid, which is analyzed using one of the most widely used program for the power system analysis, Power System Simulator for Engineering (PSS/E). See Fig. 3.

So, how does ESS realize the suppressive function to wind power fluctuation? The ESS can be controlled to compensate the active power when the active power output of the WTG drops below a specified value, so that the total active power injected into power systems by the wind farm is kept constant regardless of the wind variations.

Comparative simulation results, with and without ESS installation, were analyzed that the active power can be kept constant apparently by compensation of the ESS.

Configuration comparison of ESS connections is applied between distributed and concentrated type. From simulation results, it was easily to see that some capacity of distributed ESS might be wasted under a specific condition because the wind variations at each WTG might be different even in the same wind farm. Inversely, all capacity of the concentrated (aggregated) configuration of ESS could be used for suppressing the power flow fluctuations.

Furthermore, to power system stability problems, the ESS can be a good solution by instantly releasing or absorbing power when the wind power output is suddenly changed.

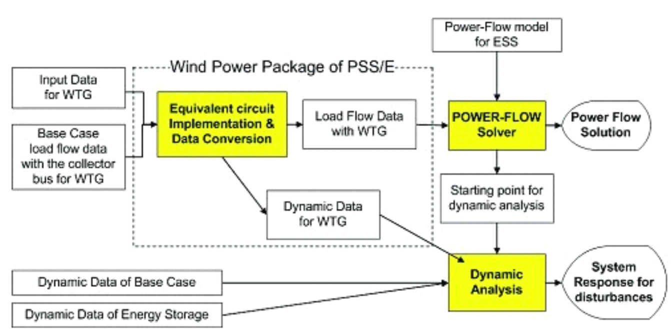

Figure 3. Overview of the implemented WTG/ESS simulation using PSS/E

V. CONCLUSION

The wind power generation, which has been expected to be a promising alternative energy source, should be assessed to guarantee error free operation and good power quality indices, when it is connected to the power grid.

Because of the fluctuation nature of the wind (velocity) and comparatively new and different types of generators, power quality issues should be considered to accomplish ‘perfection’. Case study is performed to master calculation procedure as described in IEC 61400-21 (Part 21), and effective conclusions suitable for calculation.

For mitigation of the wind generation related power quality issues, concentrated configuration of ESS seems to be one practical solution, which is not only to suppress the power fluctuation, but also improve power system stability and counteract disturbances.

VI. REFERENCES

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VII. BIOGRAPHIES

LU Yan was born in 1984 in China. He received his B.Sc. degree in University of Electronics Science and Technology of China, Chengdu, in 2007. Currently he is proceeding his M.Sc. of Control in Electric Power Engineering in Wroclaw University of Technology, Poland. His interests are power quality and fuzzy logic control.