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Power Quality on Wind Turbine Energy Output

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***Abstract*—The share of wind energy in electric energy generation increase day by day. The penetration of wind power plant in power systems has come to considerable size. On the other hand, power quality concerns are on rise. In this study, the data obtained by measurements of power quality parameters performed on a real power system are studied. The data are evaluated by the available legislations related on power quality**

Keywords— wind power plants; power quality; harmonics; voltage

I. INTRODUCTION

Increasing world population, evolving technology and rising living standards are increasing the need for global energy. On the other hand, the rising economic and environmental concerns increase the tendency to meet this energy demand with efficient systems and clean energy sources. Electric energy is an ultimate energy form that is easy to transport and distribute and does not leave any waste after consumption. Because of these features, it is the kind of energy that is expected to increase the share in the highest amount in the rising global energy need. The projections show that 70% of the expected global final energy need increase over the next 25 years is expected to take place over electric energy. Increasing accessibility of electric energy and transition from consumption of different energy sources in various sectors to consumption of electric energy are the triggers of this increase [1].

In addition to the concerns on energy supply, the sensitivity on sustainability, reliability and quality of energy is also as high as ever before. This situation is also felt in the electric energy systems. In recent years, there is been an increase regarding with these areas in industrial and academic studies [2].

Renewable energy sources distinguishes than other conventional energy sources by virtue of their economic and environmental advantages. Therefore the interest on generation electric energy by using renewable energy sources is rising day by day. Today, the number of that kind of facilities is considerably high and it is expected to be going to increase further [1].

Renewable energy sources such as wind and solar come with various disadvantages on power systems as well. Because of their intermittent nature of these sources, they give variable and unpredictable power output in energy generation. This may cause difficulties on providing supply demand balance in power systems. In addition, these facilities need special sub-systems in order to start up and control the system. These sub-system are mostly composed of semiconductor elements and they may cause various effects on power system. In order to prevent these effects from causing any damage to the power system components and the consumers in the system, various limitations are specified through the parameters determined by legislations [3].

In this study, the quality problems caused by the facilities that generate electric energy from wind, are studied. A power plant in Turkey which comprises from two wind turbine with 2,5MW installed capacity has been taken as the measurement site and quality parameters have been measured during a week. The compliance of the parameters to the limits specified in the legislation is investigated and the findings are shared.

In the next section of the paper, a brief information about power quality parameters are given. In the third part, configuration of the power plant and the measurement infrastructure is shared. After that data obtained through the system have been examined in the light of the limit values stated in the current legislation. In the conclusion part, some important findings and results are remarked.

II. POWER QUALITY PARAMETERS AFFECTED BY ENERGY PRODUCTION FROM WIND TURBINES

The wind turbines generate electric energy from the wind, which are an intermittent energy source. As it is mentioned before, the energy outputs are unstable and difficult to predict precisely. This uncertainty in the result of the intermittency of the energy source may cause various power quality problems in power systems. Within the structure of wind turbines, semiconductor elements are used to start up the system or to control frequency at the energy output. These semiconductor elements cause harmonic distortions on power system [4].

In addition, wind turbines are often integrated into power systems from distribution or sub-transmission sections. This kind of integrations are conceptualized in the literature as distributed generation. Distributed generation is contrary to decentralized generation infrastructure of conventional power systems which is designed based on unidirectional power flow. Therefore, such participations may cause bi-directional power flow in the power systems and so it may cause problems on voltage regulation [5].

The severity of the effects of wind power plants on the power system depends on the size and flexibility of the power system. The wind power plants integrated into large power systems from strong buses have low disturbing effects on the power system. On the other hand, wind power plants, which are integrated into small power systems from weak buses, may have noticeable disturbing effects on the system in case of having sufficient installed power[5].

Most of the wind power plant technologies need reactive power. The facilities installed to provide the reactive power needed by wind power plants may cause excessive excitation within the power system after the wind power plants are shut down due to any reason. Switching of these facilities also creates power quality problems.

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In this section, information about the limits defined by the legislation on the power quality parameters effected from wind power plants are given. As the legislation, the current national regulation in Turkey, "Electricity Grid Code" is taken into consideration.

A. Voltage

In the operation of power systems, the RMS voltage value is controlled within certain limits. As a result of the fluctuation in the load or the generation within the system, the RMS value of the voltage may vary. Upper and lower voltage limits are specified by legislation in order to prevent damaging on the power system components or the consumers connected to the system. In the National Electric Network Code, 10% variation of RMS voltage value is allowed. In the literature, exceeding the upper limit of the voltage is defined as overvoltage, while the voltage below the lower limit is defined as voltage sag. The RMS voltage values between these limits are considered normal operation conditions [6].

Outputs of wind power plants fluctuates depending on turbine structure and intermittency of wind speed. This fluctuations in energy generation may cause voltage variations within the system. In addition, the loss of generation resulting from the emergency shutdown of wind power plants due to the inadequate or excessively high wind speed must be met by the reserve capacities predefined by the power system operators. Voltage sags may occur as a result of imbalances that occur during the period until the balance between the supply and demand reestablished.

B. Frequency

It is important that the frequency of the grid remains stable so that power systems can be operated steadily. The frequency of the output of the wind power plants must be equal to the frequency of the grid. Otherwise, the frequency change must remain within the permitted limits. In the National Electric Network Code, the frequency is limited between certain values for different time ranges. These limits within ranges are given in Table – I. Wind power plants must satisfy these values in frequency otherwise have to be disconnected from grid [6].

TABLE I. FREQUENCY LIMITS IN NATIONAL ELECTRIC CODE REGULATION

Frequency Ranges	Minimum Operation Time
51,5 Hz ≤f≤ 52,5 Hz	10 min.
50,5 Hz ≤f<51,5 Hz	1 hour
49 Hz ≤f<50,5 Hz	continuously
48,5 Hz ≤f< 49 Hz	1 hour
48 Hz ≤f< 48,5 Hz	20 min.
47,5 Hz ≤f< 48 Hz	10 min.

C. Flicker

In its simplest terms, Flicker is defined as the sustained oscillate of voltage in a low frequency band. Flicker is an important phenomenon and must be studied carefully because it is the only quality problem that directly affects human health as well as the equipment in the system. Fluctuating wind speed, shadowed turbines or mechanical problems may cause flicker. The widening of control intervals of wing angle controlled turbines can lead to flicker problems. Wind power plants that are integrated into power systems from a weak point are more susceptible to flicker distortion.

Flicker levels for the output of wind turbines are set forth by standards and regulations. There are two different index for flicker analyzes. These are the one that for long term flicker screening (P_{lt}) and the other one is for the short term flicker (P_{st}). In the National Electric Network Code, calculation of these indices are given by formulas. P_{lt} corresponds to the average of the flicker values calculated over the voltage variations measured over 10 minutes. P_{st} is the average of the 2 minutes flickers. The limit values for these indices are shared in tables 2 and 3 according to the nominal voltage levels of the system [6].

TABLE II. FLICKER SEVERITY LIMITS

Voltage Level (V)	Flicker Severity	
	P_{st} (short term)	P_{lt} (long term)
V > 154 kV	0,85	0,63
35 kV < V ≤ 154 kV	0,97	0,72
1 kV <V ≤ 35 kV	1,0	0,8

According to the National Electric Network Code, at least 95% of the short-term flicker values, after the filtering of the temporary events occurring during the measurement period of power quality and short-term interruption, voltage dip, voltage peak, etc are filtered out from the values given in Table or 99% of the short term flicker values must be equal to 1.5 times of the regarding limit or less than that value.

Long term flicker severity can be calculated by the formula given below,

$$P_{lt} = \sqrt[3]{\frac{1}{12}\sum_{j=1}^{12} {P_{st_j}}^3} \tag{1}$$

D. Transients

Switching performed to cut-off and cut-in of the power plant or the switching of the compensation systems that provide reactive power to the system may cause transients in the power system. Especially, the switching between generators may cause severe transients. Transients can cause the sensitive components in the system to malfunction or malfunction. IEC 61400 standards are defined for transients in power systems [5].

E. Harmonics

The waveforms at the frequencies different from the waveforms of the main component of the power system, which are caused by nonlinear loads, are defined as harmonics. The distortion values for the connection points in the system are limited over some special indices. These are total harmonic distortion (THD) and total demand distortion (TDD). Generally, THD is considered on voltage evaluations and TDD is more determinant for current distortion evaluation. IEC 61000-3-2 or IEEE-519 standards specify limit values for that indices. The National Network Code are also based on those standards. The formulas for the calculation of THD and TDD values are given by (2) and (3) [7].

$$THD_v = \frac{\sqrt{\sum_{h=2}^{50} U_h^2}}{U_1} . 100 \quad (2)$$

$$TDD = \frac{\sqrt{\sum_{h=2}^{40} I_h^{\,2}}}{I_{max}} . 100 \quad (3)$$

TABLE III. HARMONIC LIMITS ACCORDINT TO VOLTAGE RANGES

Bus voltage at PCC	Individual Harmonic (%)	Total Harmonic Distortion (%)
V≤1 kV	5.0	8.0
1 kV < V ≤ 69kV	3.0	5.0
69 kV < V ≤ 161kV	1.5	2.5
161 kV < V	1.0	1.5*

* High-voltage systems can have up to 2.0% THD where the cause is an HVDC terminal whose effects will have attenuated at points in the network where future users may be connected.

Wind power systems with constant-speed turbines do not cause significant harmonic distortion in power systems. However, most of wind power systems contains drivers and converters which are comprise of semiconductor devices and these components cause harmonic distortions. Harmonic filters are used in wind power plants to obtain values at the connection points below the relevant limits.

F. VAr kontrol

A significant part of wind turbines consist of induction generators. Induction generators are preferred in wind power plants due to their lower maintenance need, lower cost and higher robustness than other generators. However, these generators absorbs reactive power in operation [5].

In order to supply the need, different compensation technologies are used in the wind power plants. During the operation of the wind power system, the compensation systems are switched on and off as needed. However, if the system is shut down for any reason and the compensation system is not as agile as it is, it can lead to overcompensation in the system. On the other hand, if the reactive power requirement can not be met, the reactive power is absorbed from the power system. This causes the lines to be unnecessarily loaded and increases power losses [5].

Reactive power is a very important tool in controlling voltage and frequency in the power systems. For this reason, a dynamic power factor control is required.

III. INVESTIGATION OF PARAMETERS OF THE MEASURED MEASUREMENTS AND POWER QUALITY

A. Wind Power system and measurement infrastructure

A schematic representation of the wind power plant from which measurements are taken is given with Fig - 1. The power plant consists of two 2500 kW wind turbines and it is connected to the network from 154 kV. Measurement Infrastructure is set at the point from 34.5kV, upstream of domestic supply. Measurement are taken from a 3-Phase class A power quality analyzer. The data to be analyzed in the study, is constituted from one-week measurement taken from the given point on schematic diagram of the wind power plant

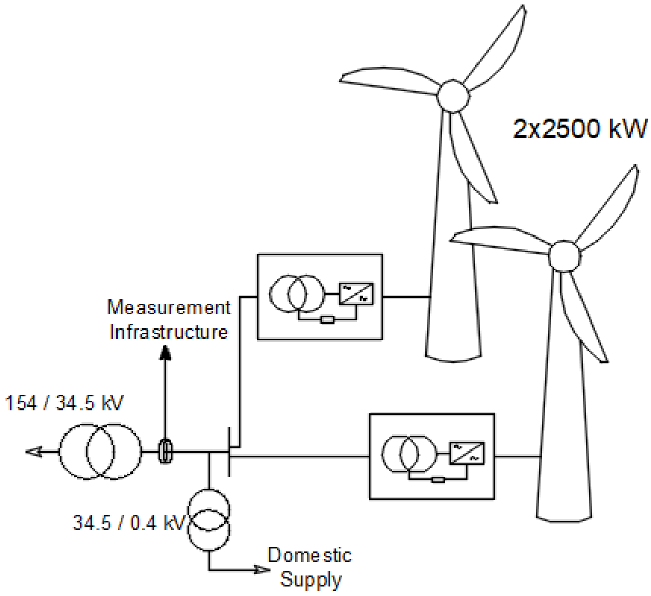

Fig. 1. Schematic representation of the power plant

B. Analyzing measured data

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

1) Voltage

The received voltage measurements are plotted with the upper and lower limit values specified in the National Network Code [6]. The measured voltage data per phase are given below.

Minimum and maximum values are given together. As it can be seen from the Fig. 2, all voltage swells and dips are instantaneous. Simultaneous voltage swells and dips may refer a transient in the system. One-sided border crossings may have been the result of changes in elements such as wind speed or reactive power demand supply balance in the system.

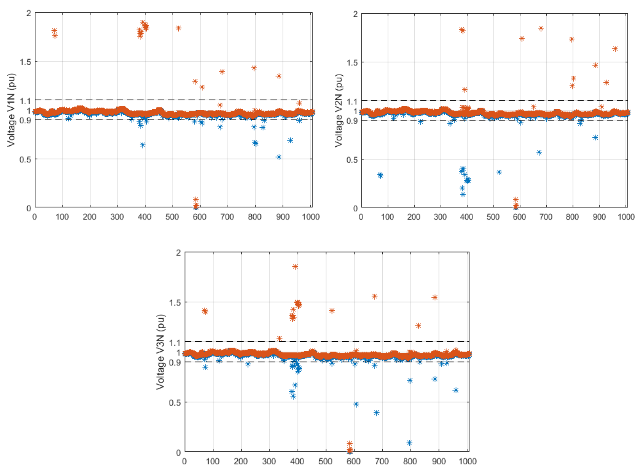

Fig. 2. Voltage measurements taken from the wind power plant

2) Frequency

The values obtained from the frequency measurements are given in Fig. 2. As it can be seen, no frequency is measured outside normal operation conditions.

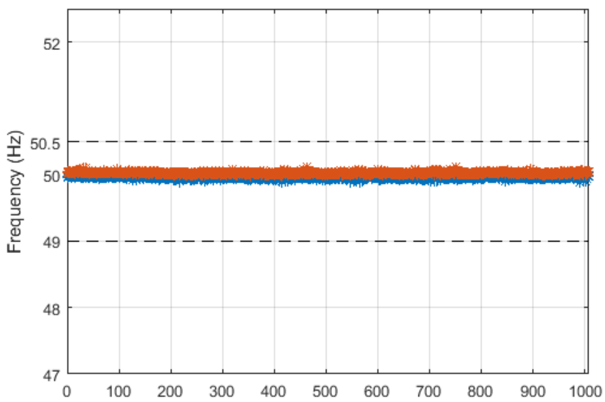

Fig. 3. Frequency measurement

3) *Flicker*

Long term and short term flicker measurement are given in Fig. 4 and 5 respectively. Although there are measures exceeding the limit values, it is possible to provide more than 95% of the limit values in the overall evaluation.

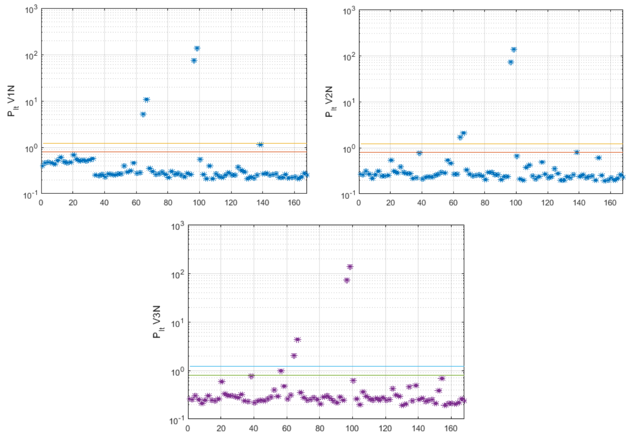

Fig. 4. Long term flicker measurement

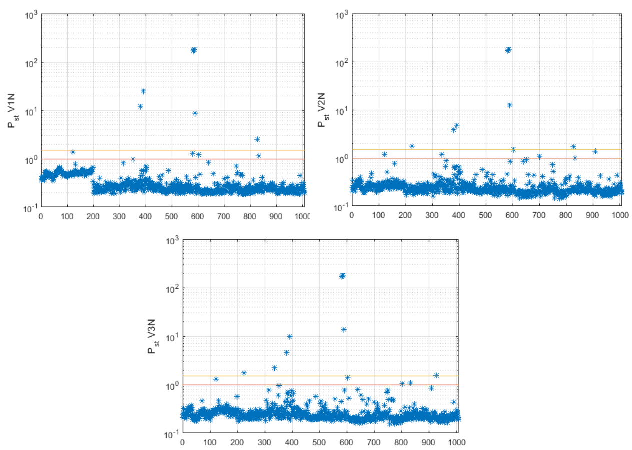

Fig. 5. Short term flicker measurement

The percentages of the measurements that below the limit value are given in Table IV. As it can be seen that the values remains after the faulty measurements eliminated provide the limits. All of the long-term and short-term flicker parameters measured for the whole phases provide the limits for the majority of over 95%.

TABLE IV. PERCENTAGE OF FLICKER MEASUREMENTS BELOW LIMITS

	P_{lt}	P_{st}
Phase 1	95.24%	99.01%
Phase 2	95.24%	98.91%
Phase 3	95.24%	98.81%

4) *Harmonics*

a) *Total Harmonic Distortion for Voltage*

Total harmonic distortion for voltage of three phase are given by Fig. 6. Although there are measures exceeding the limit values, it is possible to provide more than 95% of the limit values in the overall evaluation. The percentages of the measurements that below the limit value are given in Table V.

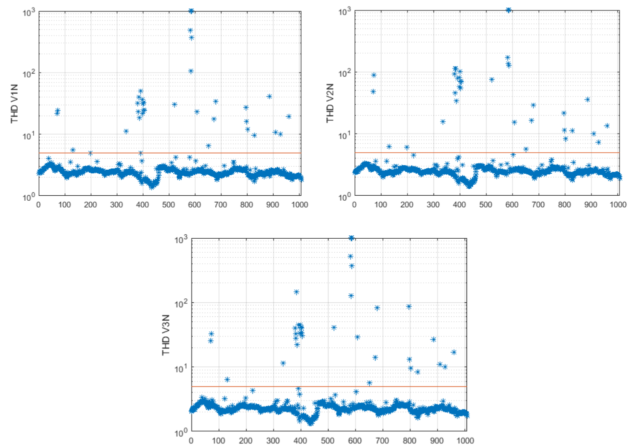

Fig. 6. Total harmonic distortion for three phase

When the values given in the table are examined, the compatibility rate of the measurements taken for all three phases is over 95%.

TABLE V. PERCENTAGE OF THE HARMONIC MEASUREMENTS PROVIDE LIMITS

	$\%THD_V > 5$
THD V1N	96.43%
THD V2N	96.43%
THD V3N	96.53%

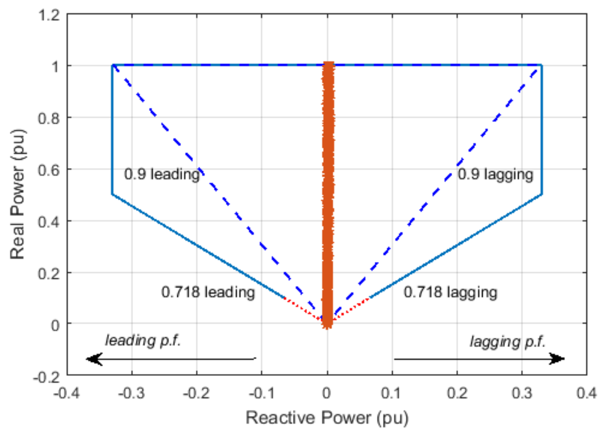

Fig. 7. Measured data for power factor

5) VAr Kontrol

Measured power data are plotted in Figure 7 with the boundary curves specified in Appendix-18 of the National Network Code. As can be seen, all of the operation points are between the specified curves. Only there are some negative active power values. These values correspond to the power absorb from the network in order to meet the internal requirements of the facility when the wind turbine is not in operation.

IV. CONCLUSION

In this study, one-week power quality measurement of a 5 MW wind power plant connected to the grid were examined. According to the findings obtained as a result of the examination of the shared data, it is understood that the power plant has output power which is in accordance with the power quality standards. However, in numerous and different technologies, it is likely that different results will be obtained in the cumulative evaluation of wind power plants. Power plants with different technologies and different configurations may have different behaviors in terms of power quality. The response given to the variation of the wind speed, or the distrtion caused by the wind power plant on the in the form of the voltage waveform may differ than each wind power plant. As a future study, it is planned to examine the power quality parameters with measurements taken from a wind power plant that is composed of different technologies and spread over a wider area.This study can provide insight into the future of the power quality in national grid which has increasing number of wind power plants.

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