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Tomasz Dróżdż
University of Agriculture in Cracow, Faculty of Production and Power Engineering
ul. Balicka 116 b, 30-149 Cracow

Stefan Kuciński
Tele and Radio Research Institute
ul. Ratuszowa 11, 03-450 Warsaw

Electromagnetic distortion test of renewable energy sources

Badania zaburzeń elektromagnetycznych źródeł energii odnawialnej

Abstract

The paper presents a number of concerns related to studies of electromagnetic interference produced by renewable energy sources. Firsty, the paper describes types of interference, focusing mainly on impulse disturbances and possible impact on people and the environment. Next, the evaluation methods and measurement equipment are discussed, followed by results of measurements of interference occurring in main power circuits of wind and small hydro-electric power plants. The summary offers recommendations to improve the quality of electricity generated by renewable power sources.

Keywords: *electromagnetic interference, renewable energy sources*

Streszczenie

W referacie przedstawiono pewne problemy dotyczące badań zaburzeń elektromagnetycznych wytwarzanych przez odnawialne źródła energii. Na wstępie omówiono rodzaje tych zaburzeń, koncentrując się głównie na zaburzeniach impulsowych oraz przedstawiono możliwe skutki ich oddziaływania dla ludzi i środowiska. Dalej omówiono metody badań zaburzeń oraz stosowane urządzenia pomiarowe. Przedstawiono również przykładowe wyniki pomiarów zaburzeń występujących w obwodach sieci energetycznej generatorów wiatrowych i generatora małej elektrowni wodnej. W podsumowaniu wskazano kierunki dalszych działań dla poprawy jakości energii elektrycznej wytwarzanej przez źródła odnawialne.

Słowa kluczowe: *zaburzenia elektromagnetyczne, odnawialne źródła energii*

1. Introduction

Energy produced by renewable energy sources like hydro and wind is affected by electromagnetic interferences that are superimposed on the power grid sine wave. These interferences are diverse in nature. The most often this would be a single pulse or a narrow sequence of pulses occurring periodically or randomly. The impulses have different shapes; the most common are an exponential or damped oscillating wave. Other types of interferences are the voltage dips and sags occurring with a specific frequency. All of these are often causing significant distortion of the grid sine wave. The line voltage contains high levels of harmonic components.

The energy grid is also a subject to pulse interferences from sources other than the generators, for example lightning and interference from the electric load. The grid transmits the interferences from the source to the receiver. It serves as a low-band filter strongly dampening short-duration impulse interference. However, interferences of longer durations are readily transmitted within the grid.

Presence of interference in the electrical grid poses a threat not just to the grid elements, but also to any device powered by the grid and in close proximity to the renewable energy sources. The likelihood of failures of electrical devices depends on both distance to the source and the nature of disturbances and the resilience of the device and the surge suppressors or other preventative devices used. Impulse disturbances pose particular danger.

They easily penetrate to the internal circuits of the device from the power supply and are difficult to control. As the level of disturbances increases, the devices malfunction or fail. These unexpected problems can also pose a threat to the operators or people in close proximity to the device. Operators may be exposed to electric shock due to insulation breach and high voltage presence on the housing or other parts, or may be hurt due to exploding components or a device malfunction.

Shorts or breakdowns caused by high-energy impulses are often accompanied by loud noise and flash caused by air discharge. They may cause uncontrollable reaction of the device operators and lead to serious accidents. Shorts and faults also pose a fire hazard further increasing danger to personnel and property.

Impact of electromagnetic and electric fields on the body is widely discussed in the literature [1, 2]. However, these publications focus on the impact of continuous harmonic fields. There is relatively little research into the impact of field impulses. It is believed that humans are more prone to the effects of pulse fields than continuous oscillating fields of certain frequencies. Defence mechanisms do not kick in fast enough to help prevent the impact of exposure to repeated impulse disturbances

The impact of such fields required further research to assess its effects and mitigation strategies. The research has to classify the nature of the disturbances and quantify their parameters and frequency. This analysis will permit assessment of the level of threat posed by the impulse disturbances to the electrical devices and persons in close proximity to them and implementations of appropriate protection.

2. Methods of measurement of electromagnetic disturbances in electrical grid

2.1. Standards for measurement methodology of the electrical supply quality

Testing of electromagnetic disturbances on electrical grids is closely related to measurements of the power supply quality. Tests are usually conducted according to methods described in PN-EN 61000-4-30 [3]. This standard documents the prescribed methods of measuring quality of the power supply and guidelines for interpreting the measurements of; frequency, RMS voltage, voltage variation, voltage dips and spikes, durations of power interruptions, asymmetry of the voltage wave, harmonic and non-harmonic disturbances and transient voltage.

The last set of parameters is related to the presence of impulse disturbances on the power grid. The standard defines the transient voltage as quantity one occurring between two permanent states over a short interval relative to the time-scale of the phenomenon. It provides characteristics of the transitional waves frequently encountered in the AC circuits, describing their amplitude and frequency parameters as well as peal voltage or current, slope of the impulse, its duration, oscillation frequency and energy. The standard lists and characterizes the detection methods, for example comparative method, envelope, moving window, and others.

The second applicable standard for measuring power supply quality is PN-EN 50160 [4]. It describes the quality requirements of low and medium voltage power grids under normal operating conditions. The scope of the standard is similar to PN-EN 61000-4-30. For transitional waves the standard lists:

- interval disturbances of the same frequency as the grid (long duration, caused by fluctuations in the load or by short-circuits),
- Transient (short oscillating or non-oscillating disturbances, often strongly dampened, lasting a few milliseconds).

Testing of the electromagnetic disturbances caused by the wind turbines are subject to PN-EN 61400-21 [5]. The standard defines and catalogues the quality parameters of the energy output of a wind generator connected to the power grid. The standards documents the following quality parameters:

- Nominal parameters (active and passive power rating, frequency and voltage),
- Output rating,

- Maximum output,
- Voltage variations (measure of light flickering, characteristics of switching),
- Harmonic levels during sustained operation.

In the chapter that describes the measurement procedures PN-EN 61400-21 establishes the conditions, general characteristics of the measurement circuits, and prescribes measurement methods and parameter computation guidelines.

2.2. Devices and schematics for measuring impulse disturbances

Impulse disturbances present in the power grids are accessed via voltage or current measurements. Spectrum analysis of these signals covers a span of several tens MHz, typically a range of up to 30 MHz. Distortion measurement devices equipped with voltage or current sensors are used. They can be spectrum analyzers, receivers, or oscilloscopes. The devices support measuring the frequency and duration of the disturbances.

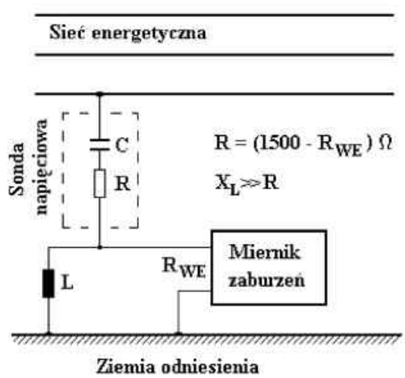

Fig. 1. Schematics for measuring asymmetrical voltage impulses in power lines
Rys. 1. Schemat układu do pomiaru niesymetrycznych napięć zaburzeń impulsowych w liniach energetycznych

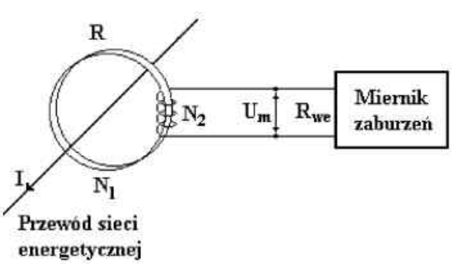

Fig. 2. Schematics for measuring current disturbances in power lines
Rys. 2. Schemat układu do pomiaru prądów zaburzeń w liniach energetycznych

Figure 1 shows the circuit for measuring asymmetrical voltage impulses in specified points of the power lines [6]. The distortion meter measures high frequency voltage between the phase wires and the reference ground. The device uses a voltage probe which strongly dampens the base 50Hz signal. The resistor value is selected to ensure a 1500 resistance between measurement point and neutral circuit as required by the standard [6]. A coil may be utilized for safety reasons. It's impedance should be many times higher than the resistance of "R".

Figure 2 shows the circuit used for measuring current disturbances in the power lines [6]. The meter utilizes a current probe, typically clamped around the tested wire. Such design permits conducting measurements without any power interruptions. The probe acts as a transformer with N1 / N2 ratio, where the tested wire acts as the primary coil and secondary coil on a ferromagnetic ring. Such a "probe" is being called "current transformer".

Specialized devices for measuring and recording interferences (including impulse disturbances) in the power grids are also available. They are referred to as testers or recorders of the grid interferences or power supply quality analyzers. They contain a set of voltage and current probes, internal battery to ensure continued operation during power interruptions or voltage variation. Some have been programmed to analyse and interpret measurement results and to present results in a user-friendly manner [6]. Figure 3 shows one such device.

Fig. 3. 1760 analyzer by Fluke
Rys. 3. Widok analizatora typ 1760 firmy Fluke

3. Results of measurements of electromagnetic disturbances from renewable energy sources

3.1. Measurement places

Measurement results of electromagnetic disturbances from renewable energy sources were performed by specialists from the Tele and Radio Research Institute of Warsaw. A series of tests on power plants located across Poland were performed. They included several wind plants and one small hydroelectric plant. Measurements included energy quality assessment including impulse disturbances of all phases to neutral/ground. Measurement methods were in accordance with standard PN-EN 61000-4-30:2005 and were performed using Fluke 1769 analyzer with a set of current and voltage probes.

3.2. Analysis of measurement results of a small hydroelectric power plant

The object of the measurements was a generator in a small hydroelectric plant. The power plant was equipped with four turbines. Its nominal power was 140kW. Output of one of the active generators was monitored during tests. Selected measurement results are presented in figure 4-6.

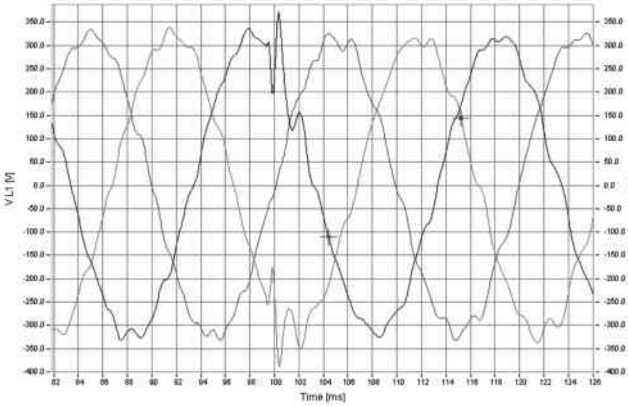

Fig. 4. A fragment of three-phase generator output showing pulse distortion. Each phase line voltage is graphed with a different color
Rys. 4. Fragment przebiegów napięciowych trzech faz z widocznym zaburzeniem impulsowym (poszczególne fazy oznaczono innym kolorem)

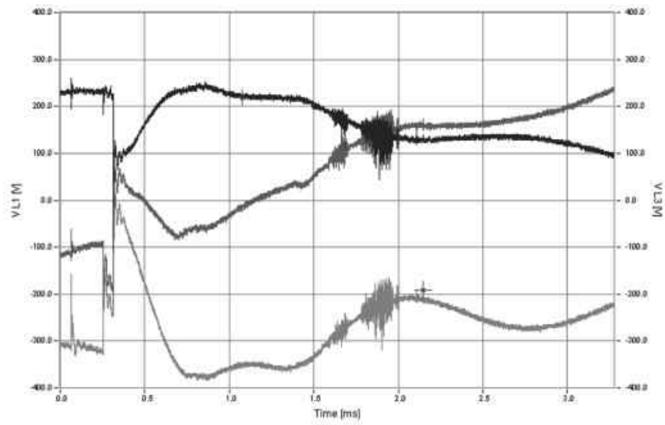

Fig. 5. Selected pulse disturbances on different phases lines
Rys. 5. Wybrane przebiegi zaburzeń impulsowych na poszczególnych fazach

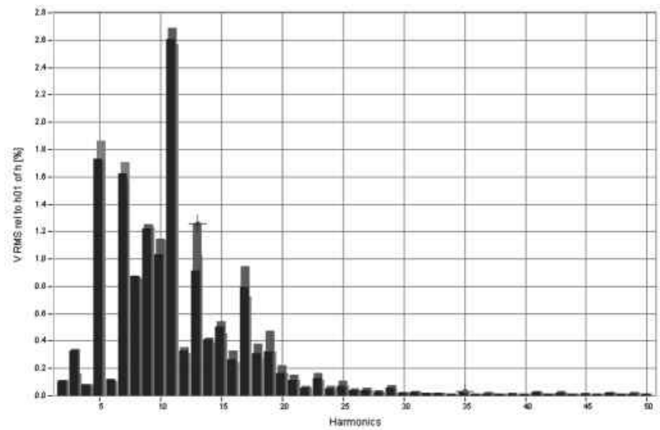

Fig. 6. Values of average harmonics of phase voltage to the 1st harmonic
Rys. 6. Uśrednione wartości poszczególnych harmonicznych napięć fazowych w stosunku do uśrednionej wartości pierwszej harmonicznej (w %)

Measurement results were analyzed using criteria documented in [7]. The analysis lead to the following conclusions:

1) The frequency range of generated voltage was 49,94 to 50,08 Hz, well within the permitted range of 50 Hz 1%.
2) Nominal voltage range was 224 V – 233 V, also well within the permitted range of Unom 10 %)
3) Light fluctuation range Plt exceeded the allowed range.
4) Registered harmonics content exceeded the allowed ranges for 9th and 11th harmonic. 11th harmonics was particularly high. Voltage distortion coefficient THD exceeded the maximum allowed value of 8%.
5) During the monitored period a large number of pulse-disturbances of the power grid sine wave were detected. The disturbances had a positive or negative polarity and amplitude of up to 500V. Their graph was consistent with that of dampened oscillations.

3.3. Analysis of measurements of a wind-generator

The tests were performed at a three-phase lines of the medium voltage of the wind-powered generator. Measurements utilized a probe connected to the low-voltage transformer coil. The generator was a 500kW synchronous-type, connected to a 72 m tall turbine tower. A selection of measurement results is shown in Fig. 7 -10.

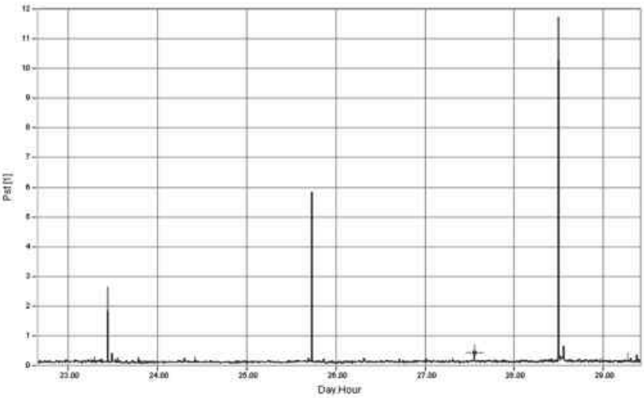

Fig. 7. Values of light flicker coefficient recorded for each phase line
Rys. 7. Wartości współczynników migotania światła (P_{st}) na poszczególnych fazach

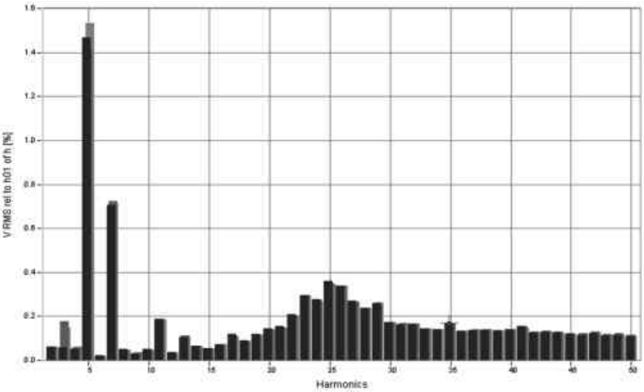

Fig. 8. Average harmonic content of each phase line relative to the averaged value of the 1st harmonic
Rys. 8. Uśrednione wartości poszczególnych harmonicznych napięć fazowych w stosunku do uśrednionej wartości pierwszej harmonicznej (w %)

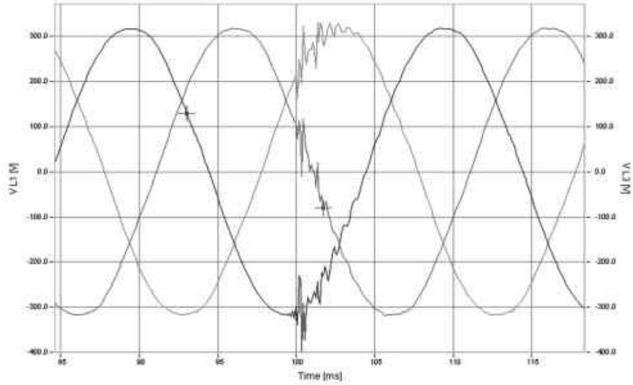

Fig. 9. Impulse disturbances superimposed on the voltage sine-wave
Rys. 9. Zaburzenia impulsowe nałożone na sinusoidalne przebiegi sieci

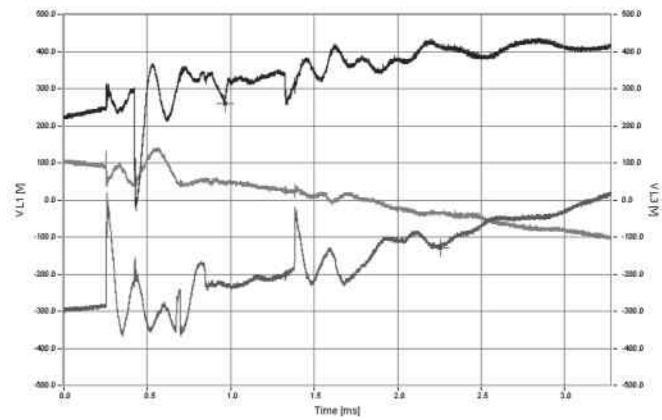

Fig. 10. Sample pulse-disturbances registered in the tested energy grid
Rys. 10. Przykładowe przebiegi zaburzeń impulsowych zarejestrowanych w badanej sieci elektroenergetycznej

Results of the measurements were analyzed in accordance with the criteria specified in [7]. The analysis leads to the following conclusions:

1) The frequency range of generated voltage was 49,9 to 50,1 Hz, well within the permitted range of 50 Hz 1%.
2) Nominal voltage range was within the permitted range, except one instance where the voltage dropped to 125V.
3) During the measurement period, three instances of exceeding the allowed light fluctuation range Plt were encountered. In one case the allowed range was exceeded five-fold.
4) Registered voltage harmonics content was within the permitted range, with 5th and 7th harmonics closest to the maximum allowed. Voltage distortion coefficient THD was also within the permitted range.
5) During the monitored period a large number of pulse-disturbances of the power grid sine wave were detected. The disturbances had a positive or negative polarity and amplitude of up to 500V. Their graphs were consistent with that of dampened oscillations.

4. Summary

The analysis of the study showed the need to continue research in this area, particularly developing methods for improving the quality of energy generated by renewable sources. Also important are methods for reducing harmonic disturbances of the hydroelectric and wind generation, in particular 5th, 5th, 9th, and 11th harmonic. Analysis confirms the need to control levels of pulse-disturbances associated with the process of generating energy via renewable soruces.

The analysis of results confirms the correlation between recorded electromagnetic disturbances and malfunctions of the generation systems. It is postulated that methods for identifying defects responsible for the disturbances through analysis of distortion patterns can be developed. Verification of this hypothesis requires extensive further study and analysis.

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