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Power quality in Fingrid's 110 kV grid

Table of contents

1 Introduction

This report defines the quality parameters of electricity in Fingrid Oyj's (hereinafter Fingrid) 110 kV grid. A customer (hereinafter Connecting Party) connecting to the high-voltage electricity transmission grid must be prepared for power quality variations at the 110 kV connection point and dimension his electrical equipment so that it can withstand the voltage and frequency variations described in this report. The Connecting Party must make sure that an exceptional voltage or frequency or a loss of voltage does not damage the Connecting Party's or other parties' electrical equipment. The Connecting Party is obliged to follow at his connection points the limits (emission current limits) defined in this report for the feeding of currents with a frequency higher than the operating frequency to the grid.

Interruptions are possible in electricity supply. The interruptions may be unexpected, caused by a disturbance or planned interruptions, for instance ones caused by maintenance work. If the customer needs uninterrupted electricity supply or better than normal quality of electricity, the customer must ensure this by means of his own systems, or, if possible, by agreeing with Fingrid on special arrangements relating to such transmission of electricity.

Finnish Electricity Market Act (588/2013) deals with issues relating to the quality of electricity and defines a defect as follows in Section 97: "Any supply of electricity is faulty, if the quality of electricity or the method of supply does not correspond to what can be considered to be agreed upon. - - -
Unless otherwise agreed, electricity distribution and other system operation as well as the supply of electricity is faulty, if the quality of the electricity does not correspond to the standards adhered to in Finland or if there have been continuous or repeated interruptions in electricity distribution or in the supply of electricity, and these interruptions cannot be considered minor when taking into account their reason and circumstances."

The Electricity Market Act makes reference to standards applied in Finland. The applicable standards do not define the quality level of voltage in a high-voltage electricity transmission grid. Standard SFS-EN 50160:2010 defines the voltage characteristics of a high-voltage grid for a voltage with an effective value of 36 kV < U_N ≤ 150 kV; the scope of application of the standard only concerns electricity distribution networks [1]. The quality parameters of electricity in the high-voltage grid, defined by Fingrid in this report, are more stringent than the limit values set for a high-voltage electricity distribution network, presented in standard SFS-EN 50160:2010.

2 Power quality in the 110 kV grid

Most of Fingrid's customers are connected to the grid with a voltage of 110 kV. Below, this report presents the quality parameters concerning the quality of the 110 kV voltage, which parameters apply to the normal state of the power system, unless otherwise specifically mentioned. A normal state is not typically valid in the following situations:

a. During serious faults which are more severe than the design criteria and in situations following such faults.

b. In force majeure circumstances (e.g. exceptional natural phenomena or disasters, measures by authorities, industrial action).

c. In disturbances caused by outsiders or in situations where the parties connected to the grid exceed the agreed emission limits substantially or do not otherwise meet the requirements for connection to the grid.

d. Exceptional interruption situations resulting from the maintenance or construction of the grid, when the grid is essentially weaker than normally.

CIGRE has published report No. 261, reference [13], on the quality of voltage. The most essential recommendations of CIGRE in view of Fingrid have been chosen for this report.

The measuring cycles of the quantities describing voltage quality have been harmonised in accordance with the SFS-EN50160 standard.

The measurement of quantities relating to voltage quality has been defined in IEC standards, references [5] and [6].

2.1 Frequency of voltage

When Fingrid's grid is connected to the synchronous Nordic system, the average of the basic frequency, measured in a 10 s period under normal operating conditions, must be in the range:

50 Hz ± 1%, 99.5% of the year.

2.2 Magnitude of voltage

The nominal value of the phase to phase voltage of the grid (U_N) is 110 kV and the typical operating voltage is 118 kV.

The 10-minute average of the effective value of phase to phase voltage is within a range of 105...122 kV for at least 95 per cent of the time, and 100 per cent of the time within a range of 100...123 kV during a measurement period of one week, with the exception of interruptions.

2.3 Voltage variations

Grid operation typically causes rapid voltage changes where the level of voltage changes in less than one second from one level to another. In normal grid operation conditions, rapid voltage changes do not exceed the values given in Table 1. Larger individual changes may occur exceptionally in particular in conjunction with disturbances.

Table 1. Rapid voltage changes under normal operating conditions of the grid.

Occurrence frequency of voltage changes	Voltage change %
once in 24 hours	< 6
less than 24 times in 24 hours	< 4
more than 24 times in 24 hours	< 3

Note. A rapid voltage drop in excess of 10 per cent is referred to as a voltage dip, see item **Virhe. Viitteen lähdettä ei löytynyt.**.

When the voltage changes occur repeatedly and quickly, they are referred to as flicker that is measured using a specific instrument [6], which gives a value P_{st} for short-term flicker severity over a measurement period of 10 minutes. The long-term flicker severity index P_{lt} is calculated from the short-term flicker severity indices in accordance with equation (1). The objective is to keep the short-term flicker severity index below 1.0 (95 per cent of the week's measurement values below 1.0) and the long-term flicker severity index below 0.8 (95 per cent of the week's measurement values below 0.8).

$$P_{lt} = \left[\sum_{i=1}^{12} \frac{P_{st,i}^{3}}{12} \right]^{\frac{1}{3}} \qquad (1)$$

2.4 Voltage dips

Voltage dip is a voltage reduction with a duration of 10 ms…1 min and a magnitude of more than 10 per cent of the voltage level preceding the dip.

There are no standard requirements concerning the number and magnitude of voltage dips since their number is highly dependent on the topology of the grid, geographical location, weather conditions, protection methods used etc. For these reasons, the number of voltage dips varies within a very wide range annually. On average, 82 per cent of voltage dips are caused by earth faults, and they can thus be seen in low-voltage networks primarily in the faulty phase, and due to the earthing method of the 110 kV grid their magnitude is on average less than 20 per cent of the phase voltage close to the fault location. However, faults in the 220 kV and 400 kV grids and multi-phase faults in the 110 kV grid cause a deeper voltage dip over a wide area.

Table 2 presents the annual anticipated average value of voltage dips in the phase voltage at the connection point to the 110 kV grid as suggestive information. The duration of a voltage dip is primarily determined by the operating time of protection. If the fault is situated in a favourable location and the protection works in the first protection zone, the duration of the voltage dip is typically less than 100 ms. When the fault is located in the second protection zone or when backup protection is activated, the duration may be considerably longer. The depth of the voltage dip is influenced by the resistance of the fault, its distance from the observation point, the short circuit power of the grid and the topology of the grid. Moreover, it must be remembered that the dip is transferred through transformers. Consumption devices connected on the low-voltage side only see a part of the 110 kV voltage dip, because the zero-sequence component of voltage is not transferred through most of the transformers.

Table 1. Annual average number of voltage dips in 110 kV phase voltage categorised on the basis of depth and duration of dip.

Dip	< 20 ms	20...100 ms	0.1...0.5 s	0.5...1 s	1...5 s
10...< 15 %	30	15	5	5	1
15...< 30 %	20	20	5	5	1
30...< 60%	10	10	5	2	1
60...< 99%	5	5	1	1	0

2.5 Overvoltages

No target variation limits have been defined for overvoltages in the grid in this report, because overvoltages are exceptional in nature and they cannot be restricted reasonably precisely in an overhead line grid. Only statistical and other information can be given of overvoltages.

2.5.1 Temporary overvoltages

The most important reason for overvoltage is a voltage rise in the intact phases during an earth fault. Depending on the earthing method used in the grid, voltage may rise up to 1.8 times as high as before the fault. The 110 kV grid is not effectively earthed, and only some of the neutral points of transformers in the 110 kV grid are earthed. The reason for this is the need to restrict the level of earth fault currents and hazardous voltages. Normally, there is a connection from every point in the 110 kV grid to an earthed 110 kV neutral point.

It is temporarily possible that a connection to earth has been disconnected for instance after grid faults, and in such cases the intact phases may have a voltage as high as the phase to phase voltage during an earth fault. In practice, the voltage rise is normally restricted to a range of 1.2...1.5*U_N, but the maximum value of 1.8 p.u. should be used as the design criterion of equipment connected to the grid. Since these overvoltages are related to faults occurring in the grid, as are voltage dips, their occurrence frequency can be compared to the occurrence frequencies given in Table 2.

2.5.2 Switching and lightning overvoltages

Most switching overvoltages in the 110 kV grid are created when capacitors are switched to the grid and while autoreclosing lines. The neutral point of shunt capacitors used in the grid is not usually earthed. When a capacitor is switched on, the temporary phase to earth voltage may reach a value which can be up to 1.8 times as high as the peak value of phase voltage before the switching. The overvoltage is oscillating (300...700 Hz), and it typically dies away during one cycle. In some cases, overvoltage oscillation may be magnified up to twice the original value as a result of resonances while transferred to the low voltage level. Equipment and systems connected to the grid must withstand overvoltages of this magnitude without failure.

Relatively large overvoltages – up to more than 3 times the peak value of phase voltage – may be created in conjunction with line switching, especially during high-speed autoreclosing. However, the likelihood of such overvoltages is small, and their duration is in the millisecond range.

In an overhead line grid, lightning overvoltages are primarily restricted by the dielectric strength of the grid and surge arresters at substations. For this reason, it can be stated only roughly that the amplitude of lightning overvoltages is less than 4 p.u. at substations and less than 6 p.u. along the line.

2.6 Voltage unbalance

The 10-minute average of the negative sequence component of the voltage in a three-phase system is less than 2 per cent of the phase voltage of the nominal voltage (95 per cent value of the values during a measurement period of one week).

In order to achieve this target, the magnitude of the negative sequence component of the load current of the Connecting Party may be at the most in accordance with Table 4. If the nature of the load differs from this, the matter must be agreed upon with Fingrid separately.

2.7 Harmonics of voltage and current

When assessing the levels of harmonics, 10-minute averages compiled during a measurement period of one week are used. 99 per cent of these average values must be smaller than the values given in Table 3.

The maximum values of harmonic currents, with respect to the reference current, which the Connecting Party can feed into Fingrid's grid are given in Table 4. The reference current is calculated on the basis of the average active power at the Connecting Party's connection point, using the nominal voltage and power factor 1.

The psophometric value of phase current refers to a value specified in reference [9] in accordance with equation (2):

$$I_p = \frac{1}{1000} \cdot \sqrt{\sum_{h=1}^{h=N} (p_h \cdot I_h)^2} \qquad (2)$$

where:

I_h	h^{th} harmonic component of phase current
h	harmonic order
N	the number of harmonics included in the calculation is 100
p_h	frequency weighting coefficient at harmonic h, Figure 1 and Appendix 1

Table 3. Maximum levels of harmonic voltages in the 110 kV grid, per cent of the nominal voltage.

Not multiples of 3		Multiples of 3		Even harmonics	
n	%	n	%	n	%
5	3.0	3	3	2	1.0
7	2.5	9	1.3	4	0.7
11	1.7	15	0.5	6	0.5
13	1.7	21	0.5	>6	0.3
17	1.5	>21	0.3		
19	1.5				
23	0.8				
25	0.8				
>25	0.5				
Total harmonic distortion of voltage				< 3 %	

Table 4. Emission current limits permitted for the Connecting Party, per cent of the Connecting Party's reference current.

Total distortion of current	6 %
Psophometric value of phase current	5 A
Negative sequence component of current	20 %

2.8 Interharmonics

Interharmonics are normally much smaller than harmonics, and interharmonics do not have limit values specified by standards. Interharmonics are created for instance by arc furnaces, welding machines and rapidly changing converter drives. So far, there has not been a need to set limit values for interharmonics.

3 Availability and transmission reliability

The concept of availability is related to a device or system, and it refers to the duration that the device or system has been in operation and out of operation. As a parameter, availability is ambiguous. If a single network is examined from one year to another, the availability figure primarily describes the relative duration that the device or system has been out of operation because of maintenance, not so much the quality of service. In a mesh grid, availability does not reveal directly the impact on the transmission capacity of the grid, because there are always parallel routes even if a certain circuit is out of operation. The overall availability of a connection point is measured by monitoring the number and duration of disturbances and maintenance outages.
Transmission reliability can be assessed point-specifically or user-specifically. User-specific assessment is sensible for the end users typically in a distribution network, but in a transmission grid it is more meaningful to examine transmission reliability by means of the parameters of the connection points.

3.1 Connection point specific indices

System Average Interruption Duration Index (SAIDI):

$$SAIDI = \frac{\mathrm{Annual\_sum\_of\_disturbance\_interruption\_durations\_at\_connection\_points}}{\mathrm{Number\_of\_connection\_points}}$$

Target value for average interruption duration: < 6 min per connection point per year.

System Average Interruption Frequency Index (SAIFI) (only disturbances in excess of 30 s):

$$SAIFI = \frac{\mathrm{Annual\_total\_number\_of\_disturbance\_interruptions\_at\_connection\_points}}{\mathrm{Number\_of\_connection\_points}}$$

Target value for system average interruption frequency: ≤ 1 interruption per connection point per year.

3.2 Energy-based indices

System minute, SM (CIGRE):

$$SM = \frac{\mathrm{Unsupplied\_energy} \cdot 60}{\mathrm{Maximum\_consumption\_by\_system}} \cdot \mathrm{min}$$

Unsupplied energy (MWh), and maximum consumption by system (MW).

Target value: SM < 2 minutes.

3.3 Indicators submitted to the Energy Authority

The Energy Authority has issued, by virtue of Section 27 (3) of the Electricity Market Act (588/2013), a provision on the indicators of system services in electricity system operations. Fingrid delivers the indicators to the Energy Authority annually. The indicators also deal with the quality of electricity and are publicly available on the website of the Energy Authority.

References

[1]. CENELEC EN 50160:2010 – Voltage Characteristics of Electricity supplied by public electricity networks. European standard (supersedes EN 50160:2007).

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[4]. IEC 61000-4-7, 2009, Electromagnetic compatibility (EMC) - Part 4-7: Testing and measurement techniques - General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto

[5]. IEC 61000-4-30, 2008, Electromagnetic compatibility (EMC) - Part 4-30: Testing and measurement techniques - Power quality measurement methods

[6]. IEC 61000-4-15, 2010, Electromagnetic compatibility (EMC) - Part 4-15: Testing and measurement techniques - Flickermeter - Functional and design specifications

[7]. IEC 61000-2-12, 2003-04: Electromagnetic compatibility (EMC) – Part 2-12: Compatibility levels for low-frequency conducted disturbances and signaling in public medium-voltage power supply systems.

[8]. IEC 61000-2-8, 2002, Voltage dips and short interruptions on public electric power supply systems with statistical measurement results, Technical Report.

[9]. CCITT, "Danger and Disturbance", Directives Volume VI, Geneve 1989.

[10]. NVE,Dokument nr 13-2004, Forskrift om leveringkvalitet i kraftsystemet, Oslo, December 2004

[11]. EURELECTRIC Power quality in European Electricity Networks, 1st edition, report 2002-2700-0005. Feb. 2002.

[12]. Guide to quality of electricity supply for industrial applications, part 2. Voltage dips and short interruptions. Paris, France: UIE, 1996.

[13]. Power Quality Indices and Objectives, CIGRE Publication No 261, October 2004

Appendix 1 Psophometric factors

h	P_h	h	P_h	h	P_h	h	P_h	h	P_h
1	0.7	21	1109	41	698	61	513	81	161.3
2	8.9	22	1072	42	689	62	501	82	144.5
3	35.5	23	1035	43	679	63	487	83	130.3
4	89.1	24	1000	44	670	64	473	84	116
5	178	25	977	45	661	65	458.5	85	104.2
6	295	26	955	46	652	66	444	86	92.3
7	376	27	923	47	643	67	428	87	82.4
8	484	28	905	48	634	68	412	88	72.4
9	580	29	881	49	625	69	394	89	64.3
10	661	30	861	50	617	70	376	90	56.2
11	733	31	842	51	607	71	355.5	91	50
12	794	32	824	52	598	72	335	92	43.7
13	851	33	807	53	590	73	313.5	93	38.8
14	902	34	791	54	580	74	292	94	33.9
15	955	35	775	55	571	75	271.5	95	30.1
16	1000	36	760	56	562	76	251	96	26.3
17	1035	37	745	57	553	77	232.5	97	23.4
18	1072	38	732	58	543	78	214	98	20.4
19	1109	39	720	59	534	79	196	99	18.2
20	1122	40	708	60	525	80	178	100	15.9

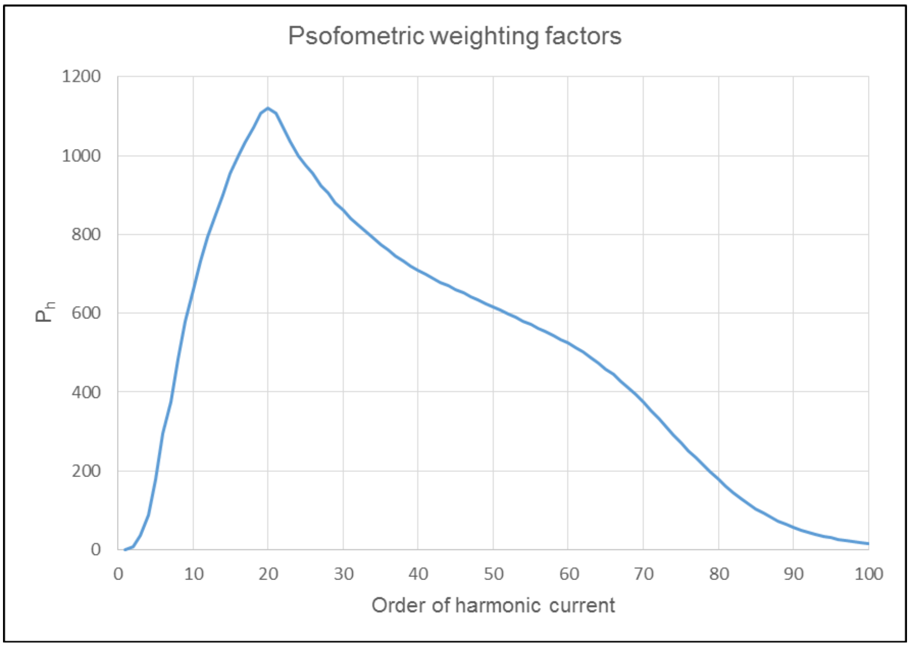

Figure 1. Psophometric weighting factors at different harmonics. The exact values are given in the table.