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INFLUENCE OF BIOGAS COGENERATION PLANT TO THE POWER QUALITY OF POWER DISTRIBUTION NETWORK

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Abstract: *This paper presents the analysis of power quality issues of biogas cogeneration plant connected to the 20kV power distribution network. Analysis is based on the results of two sets of measurements - during the first (test) connection to the grid and one year later, during the normal operation of the plant. Methodology presented in the paper consists of the combination of power quality measurements and calculations based on parameters of power distribution network and the cogeneration plant. Obtained results are compared with admissible levels prescribed in corresponding standards and technical guidelines. The conclusions confirm that proposed methodology may be used as a useful tool, for both power distribution companies and investors in renewable sources.*

Key Words: ***power quality, distributed generation, renewable sources, voltage fluctuation, harmonic emissions***

1. INTRODUCTION

Biogas is the product of the anaerobic fermentation of organic material in a fermenter. This gas contains 45-70 percent of methane CH_4. During the combustion, the amount of emitted CO_2 merely corresponds to the amount which the substrates absorbed during growth [1]. Cogeneration plants that produce power using biogas prevent emissions that would otherwise be emitted during the combustion of fossil fuels. This type of a plant is shown in the Fig. 1.

Analysis presented in the paper are performed in "Alltech" Subotica, international company that mainly produces provender and bakery yeast. As a by-product in the production, a large amount of water rich with anaerobic bacteria is created. By purification of that water, biogas is released, which could be used to produce electricity and additional heat, which can be re-used in the purification process. In this way, the plant is able to further exploit its potential and with some investment to be connected to the distribution system in the function of small power plant (SPP) with renewable energy source.

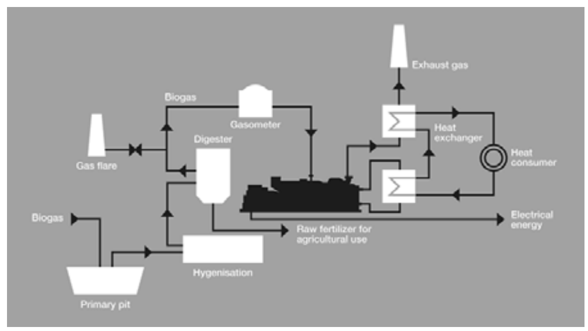

Fig. 1. *Biogas cogeneration plant principle scheme*

This cogeneration plant consist of two identical gas generators, U_n = 0.4 kV and P = 700 kW each, connected to the 0.4 kV bus of transformer 20/0.4 kV/kV. In this transformer station there is a main connecting switch from which 20kV cable departs to the distribution facility in SPP "Alltech", where the connection point to the distribution network is located (Fig. 2).

In order to put SPP into operation in the distribution system, it is necessary to meet the prescribed regulations [2]. One of the issues considers the impact of SPP on power quality. In order to verify compliance with these requirements, it is necessary to carry out measurements of specific electrical parameters according to the relevant standard [3].

2. CRITERIA FOR CONNECTION OF SMALL POWER PLANT TO THE DISTRIBUTION NETWORK

The technical requirements for connection of small power plant to distribution network is defined by the *Technical Recommendation No. 16* issued by Directorate of Electricity Distribution [2]. This recommendation contains several criteria that must be met in order to create the necessary conditions for connection of SPP to the network and one of them is the criterion of allowed harmonic currents and voltages (paragraph 5.7, [2]).

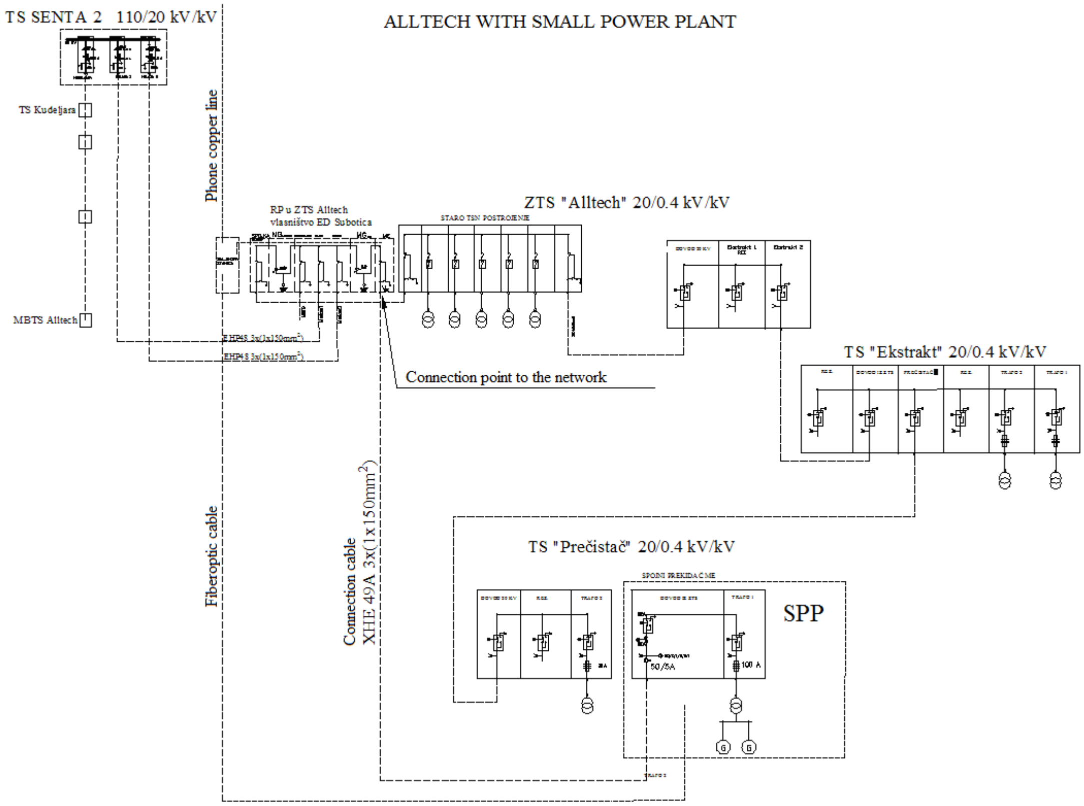

Fig. 2. *Single-pole scheme of the small power plant connected to the distribution network*

Current criterion is evaluated by the following expression:

$$I_{vhdoz} = i_{vhs,v,\mu} \cdot S_{ks} \,. \quad (1)$$

where

I_{vhdoz} is the allowed value of the harmonic current at the voltage level of the generator, [A],

$i_{vhs,v,\mu}$ is the value of the harmonic current reduced to the short circuit power at the connection point to the distribution network, [A/MVA],

S_{ks} is the value of three-phase short-circuit power (equal to "*initial symmetrical short-circuit power*" defined in [4]) at the connection point to the distribution network, [MVA].

In the case when several SPPs or generators are to be connected to the distribution network at the same point of connection, the following expression needs to be applied:

$$I_{vhdoz} = i_{vhs,v,\mu} \cdot S_{ks} \cdot \frac{S_i}{S_{gsum}} \,. \quad (2)$$

S_i is the apparent power of particular SPP/ generator at the connection point to the distribution network,

$S_{gsum} = \sum_{i=1}^{n} S_i$ is the sum of apparent powers of all SPPs/ generators connected to the same connection point to the distribution network.

Technical Recommendation No. 16 gives the values for $i_{vhs,v,\mu}$, for different voltage levels (Table 5.7 in [2]). These currents are maximum permissible values at the connection point to the network and should be multiplied with three-phase short-circuit power at the same point before being used for comparison with the measurement results.

When it comes to harmonic voltages, *Technical Recommendation No. 16* gives explicit values of maximum permissible voltages for each harmonic order (Table 5.7b in [2]), and these values can be used without any further calculations.

3. CALCULATION OF THREE-PHASE SHORT-CIRCUIT POWER ACCORDING TO SRPS EN 60909

As discussed in Chapter 2, the value of three-phase short-circuit power at the connection point to the distribution network (bus A, Fig. 3) is important for calculations of maximum permissible values of harmonic currents.

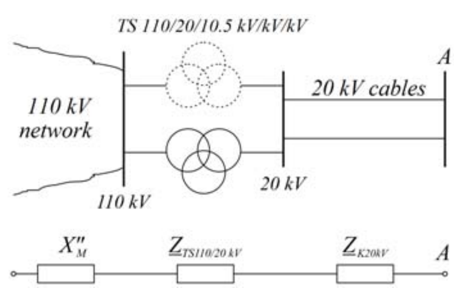

Fig. 3. Equivalent scheme for calculation of three-phase short-circuit power at the connection point to the distribution network

Generally, three-phase short-circuit power is given by [4]:

$$S_{ks} = \sqrt{3} \cdot U_n \cdot I''_{k3} \quad (1)$$

where

U_n is the rated line voltage of power supply network,

I''_{k3} is the subtransient three phase short circuit current.

According to the equivalent scheme from Fig. 4, three-phase short-circuit power at point A can be also calculated as follows:

$$S_{ks} = \sqrt{3} \cdot U_{nA} \cdot \frac{c \cdot U_{nA}}{\sqrt{3} \cdot |\underline{Z}_{ek}|} = \frac{c \cdot U_{nA}^2}{|\underline{Z}_{ek}|} \quad (2)$$

with

$$\underline{Z}_{ek} = jX''_M + \underline{Z}_{TS110/20\text{kV}} + \underline{Z}_{K20\text{kV}} \quad (3)$$

where

c is the voltage factor,

U_{nA} is the rated line voltage at point A,

$\underline{Z}_{ek}$ is the fault loop total impedance,

X''_M is equivalent reactance of feeding network (the reactance of the network is to be considered dominant over the resistance, so it is used that $Z''_M = X''_M$,

$\underline{Z}_{TS110/20kV}$ is equivalent impedance of transformer station TS Senta 2,

$\underline{Z}_{K20kV}$ is equivalent impedance of 20 kV connection cables.

All the impedances should be calculated for voltage level of point A (20 kV).

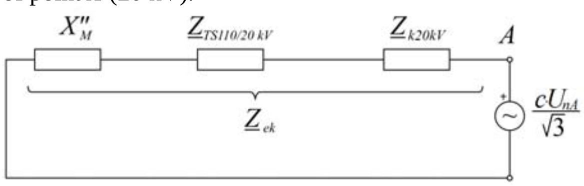

Fig. 4. *Equivalent circuit diagram with equivalent voltage source [4]*

Data available for calculations are:

- parameters of 20 kV cables,
- parameters of transformers in transformer station TS Senta 2 110/20/10.5 kV/kV/kV,
- initial symmetrical short-circuit current I''_{k3} at 110kV bus bars.

The starting point in determining the value of I''_{k3} was the data taken from the documentation [5] (Table 8.1a). As the planned value for this current is 4 kA for the year 2014, for the existing network conditions the slightly lower value is adopted, 3.8 kA.

Since this current is known, the equivalent impedance Z''_M of the network (positive-sequence short-circuit impedance) at the feeder connection point should be determined by:

$$X''_M = \frac{c \cdot U_{nM}}{\sqrt{3} \cdot I''_{k3}} \quad (4)$$

where

c is the voltage factor,

U_{nM} is the rated line voltage of power supply network,

I''_{k3} is the subtransient three phase short circuit current.

Voltage factor c is the ratio between the equivalent voltage source and the nominal system voltage U_n divided by $\sqrt{3}$, [4]. Since the value of 3.8 kA of short-circuit current corresponds the nominal voltage at the short-circuit location (as in [5]), the voltage factor c in (4) is considered to be 1.

When calculating the equivalent impedance of transformer station TS Senta 2, it is necessary to consider the most critical case. Fig. 3 shows the network with a transformer station that includes two transformer units. An outage or planned exclusion of one of the transformers will cause the power three-phase short circuit at point A to be reduced. If the generator connects such weakened network, the allowed values of harmonic currents will be less than in the case of full network. Therefore, the transformer with lower impedance should be exempt from the fault loop in order to minimize the short circuit current at the connection point of SPP.

After calculating the values of equivalent impedance (reactance) of the network, equivalent impedance of transformer station and the equivalent impedance of connection cables, $\underline{Z}_{ek}$ is found by (3). Thereafter, the actual value of three-phase short-circuit power at the connection point can determined as (2). In this step it is very important to pay attention to voltage factor c in terms of finding a minimum short-circuit power S_{ks}. According to [6], the minimum voltage for 20 kV system in normal operation is 19 kV, i.e. $0.95U_n$. Therefore, voltage factor c should now take the value of $c_{min} = 0.95$.

All the conclusions stated above lead to the calculation of minimum short-circuit power $S_{ks} = 144$ MVA which enables allowed values of the harmonic currents I_{vhdoz} to be as low as possible. In this way, it is ensured that if SPP meets the harmonic current requirements which correspond the minimum short-circuit power, then it will surely meet these requirements in the case of any short-circuit power.

4. INFLUENCE OF SPP ON THE POWER QUALITY OF DISTRIBUTION NETWORK

Measurements are performed with state-of-art power analyzers at conditions that guarantee measurement accuracy and according to the methods from standard SRPS EN 50160.

Fig. 3. *Measurement point No. 1*

Fig. 4. *Measurement point No. 2*

4.1. The results of the first measurement set during the first (test) connection of the plant

Following tables present some of the measurement results for two regimes – before the connection of the SPP to the network (Table 1) and after, during the operation of one out of two generators (Table 2).

Table 1. *Basic electrical parameters at measurement point No. 2 before the connection of the SPP*

Parameter	Min	Max	Average
f [Hz]	49.97	50.01	49.99
U_1 [V]	20500	20620	20556
U_2 [V]	20500	20640	20557
U_3 [V]	20480	20600	20540
THD_U [%]	0.0	1.0	0.563
THD_V [%]	0.0	1.0	0.285
V_{unb} [%]	0.0	0.2	0.028
Pst_1	0.0	0.0	0.0
Pst_2	0.0	0.0	0.0
Pst_3	0.0	0.0	0.0

Table 2. *Basic electrical parameters at measurement point No. 2 during the operation of one of the generators*

Parameter	Min	Max	Average
f [Hz]	49.98	50.02	50.00
U_1 [V]	20560	20660	20606
U_2 [V]	20540	20660	20597
U_3 [V]	20500	20620	20571
I_1 [A]	1.0	13.45	9.29
I_2 [A]	1.1	14.10	9.82
I_3 [A]	1.1	13.60	9.61
P [kW]	-9.3	-483.35	-333.45
Q [kVAr]	28.89	87.67	71.88
S [kVA]	37.73	490.31	342.19
THD_I [%]	4.5	41.6	7.96
THD_U [%]	0.0	0.8	0.729
THD_V [%]	0.0	1.2	0.538
V_{unb} [%]	0.0	5.4	0.098
Pst_1	0.0	0.21	0.010
Pst_2	0.0	0.27	0.012
Pst_3	0.0	0.20	0.013

Harmonic voltages were measured in both regimes, in order to detect the influence of particular generator to the power distribution network. All measured values are found to be zero except for 5th harmonic voltage, Table 3.

Table 3. *Permissible and measured values of harmonic voltages*

Harmonic order [ν]	Permissible values of harmonic voltages for 10, 20 and 35 kV network [% U_n]	Values in the regime without generator connected to the network [% U_n]	Values in the regime with generator connected to the network [% U_n]
5	0.5	0.535	1.008
7	1	0	0
11	1	0	0
13	0.85	0	0

As the value of the 5th harmonic voltage in the regime without connected generator was 0.535%·U_n and following the 1.008%·U_n in the regime with connected generator, the value of the 5th harmonic voltage that is injected by generator alone is 0.473%·U_n. This value is below the permissible value, so criterion considering harmonic voltages is fulfilled.

Values of permissible currents injected to the network by generator are calculated according to the previously calculated minimum three phase short circuit power at the connection point S_{ks} = 144 MVA and equation (1). These values are presented in Table 4, side-by-side with actual values, measured on the site.

Table 4. *Permissible and measured values of harmonic currents*

Harmonic order [ν]	Permissible values of SPP's harmonic currents[A]	Permissible values of harmonic currents for one generator [A]	Measured values of harmonic currents[A]
2	4.176	2.088	0.01
4	1.296	0.648	0.24
5	4.176	2.088	1.62
6	1.728	0.864	0.00
7	5.904	2.952	0.54
8	0.576	0.288	0.00
10	1.008	0.504	0.00
11	3.744	1.872	0.18
12	0.720	0.360	0.00
13	2.736	1.368	0.07
14	0.432	0.216	0.00
16	0.432	0.216	0.00
17	1.584	0.792	0.06
18	0.288	0.144	0.00
19	1.296	0.648	0.04
20	0.216	0.108	0.00

These results show that all the measured harmonic currents are within permissible levels. Therefore, it is concluded that this SPP meets the necessary requirements considering harmonic contents in both voltage and current injected by the generator.

4.2. The results of the second measurement set during the normal operation of the plant

The aim of the second set of measurements, which was carried out one year after the test connection (described in chapter 4.1.), was to investigate the power quality aspects of the small power plant during the normal operation a after period of exploitation. The obtained results were compared to the harmonic voltage limits prescribed in standard SRPS EN 50160. As for the currents, since the standard SRPS EN 50160 does not take them into account, the results were compared to the values prescribed in standard IEEE 519 [7].

Table 5. *Basic electrical parameters at measurement point No. 2 during the operation of one of the generators*

Parameter	Min	Max	Average
f [Hz]	49.95	50.03	49.99
U_1 [V]	20480	20660	20567
U_2 [V]	20560	20740	20651
U_3 [V]	20560	20760	20654
I_1 [A]	1.37	19.24	10.46
I_2 [A]	1.69	19.06	10.56
I_3 [A]	1.05	18.57	9.99
P [kW]	49.06	675.95	369.31
Q [kVAr]	5.00	35.1	7.14

S [kVA]	0.4	1.2	0.779
THD_I [%]	0.4	1.1	0.778
THD_U [%]	49.95	50.03	49.99
THD_V [%]	20480	20660	20567
V_{unb} [%]	20560	20740	20651
Pst_1	20560	20760	20654
Pst_2	11840	11940	11893
Pst_3	11840	11940	11891

Table 6. *Measured values of harmonic voltages compared to the permissible values according to Standard SRPS EN 50160*

Harmonic order [v]	Measured values of harmonic voltages [%]	Permissible values according to SRPS EN 50160 [%]	+ / -
2	0	2	-
3	0.1034	5	-
4	0	1	-
5	0.6775	6	-
6	0	0.5	-
7	0.3112	5	-
8	0	0.5	-
9	0	1.5	-
10	0	0.5	-
11	0.1071	3.5	-
12	0	0.5	-
13	0.0033	3	-
14	0	0.5	-
15	0	0.5	-
16	0	0.5	-
17	0	2	-
18	0	0.5	-
19	0	1.5	-
20	0	0.5	-

Table 7. *Measured values of harmonic currents compared to the permissible values according to Standard IEEE 519*

Harmonic order [v]	Measured values of harmonic currents[%]	Permissible values according to IEEE 519 [%]	+ / -
2	0.0316	1.0	-
3	0.7644	4.0	-
4	0.0001	1.0	-
5	6.6750	4.0	+
6	0	1.0	-
7	1.6243	4.0	-
8	0	1.0	-
9	0.2022	4.0	-
10	0	1.0	-
11	0.6502	2.0	-
12	0	0.5	-
13	0.2196	2.0	-
14	0	0.5	-
15	0.0045	2.0	-
16	0	0.5	-
17	0.3112	1.5	-
18	0	0.375	-
19	0.3112	1.5	-
20	0	0.375	-

From the previous tables, Table 7 and Table 8, it is concluded that after one year of exploitation, this SPP meets the requirements, with exception of 7th harmonic current which is slightly higher than permissible value from IEEE 519. However, since the harmonic voltages fulfill the national standard SRPS EN 50160, it is considered that the plant meets the standards, in addition to fulfillment of requirements from *Technical Recommendation No. 16*.

5. CONCLUSION

This paper presents a methodology to analyze the possibilities of including SPP with renewable energy sources to the power distribution network. During the test conducted during the first connection of generators to the distribution network, adequate measurements and analysis were carried through. Special attention was put on the calculation of certain parameters that can affect conclusions about the possibility or impossibility of connecting a small power plant to the distribution network. A year later, the test was repeated, but this time to ensure that during exploitation this small power plant keeps the power quality parameters within ranges prescribed in standards. It is shown that in the case of SPP within "Alltech" factory, all the requirements from relevant standards and technical recommendations are fulfilled.

The ultimate goal is to develop a methodology based on a combination of measurements and calculations in accordance with the standards and recommendations that will assist investors in renewable energy and also the power distribution companies when deciding whether to approve connection of SPP to distribution network or not.

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