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Active Power Losses in Three-Phase Cable Power Lines

***Abstract**. This paper deals with the power quality in a distribution grid. It is aimed to analyze active power losses that arises in the distribution grid of 22 kV. The active power losses are influenced by various adverse effects such as the load voltage unbalance, the load power factor, and the higher harmonics. The influence of these adverse effects was analyzed by the simulation model that was created in the simulation program Matlab – Simulink. The simulation was performed for three types of power line cable conductors, their different lengths, different types of active power consumption and different values of adverse effects that are mentioned above. Pursuant to data, obtained from the real measurement on an existing part of the distribution grid, another simulation was performed. Based on the individual analyzes of the real measurement, the financial losses during a certain period were calculated.*

Streszczenie.** W artykule analizowano straty mocy czynnej w sieci rozdzielczej 22 kV. Analizowano nierównowagę napięć obciążenia, współczynnik mocy I obecność harmonicznych. Przeprowadzono symulację dla trzech typów linii kablowych o różnej długości I różnych poborów mocy. Inalizowano też koszty.* ***Straty mocy czynnej w trójfazowej linii kablowej

Keywords: power quality; active power losses; load unbalance; power factor; harmonics.
Słowa kluczowe: straty mocy, jakość energii, linie kablowe.

Introduction

In modern electrical power systems, electricity is produced at power plants, transmitted through a high voltage network, and finally distributed to consumers. Electricity is one of the key elements of any economy, industrialized society or country [1]. A modern power system should provide reliable and uninterrupted services to its customers at a rated voltage and frequency within constrained variation limits that are defined in standard EN 50160. If the supply quality suffers a reduction and is outside those constrained limits, sensitive equipment might trip, and any motors connected on the system might stall. The electrical system should not only be able to provide cheap, safe and secure energy to the consumer, but also to compensate for the continually changing load demand [1-3].

A number of customer's equipment pollute the supply system as they draw non-sinusoidal current and behave as nonlinear loads. Power quality is quantified in terms of voltage, current or frequency deviation of the supply system. Some power quality problems can be voltage harmonics, sag/dip, swell, fluctuations, unbalance, flickers and so on. Because of for example these problems, power quality has become an important area of study in electrical power systems, especially in electric distribution and utilization systems. It has created a great challenge to both the electric utilities and manufacturers. Utilities must supply consumers with good quality power for operating their equipment satisfactorily, and manufacturers must develop their electric equipment either to be immune to such disturbances or to override them [4-7].

All electrical power systems are connected by transmission power lines and distribution power lines. Voltage drops and power losses occur by the flowing current through these power lines [8]. In the ideal case, this current is created by only the active component. The current value can be increased by additional components. The additional components are reactive current component, current of harmonics and non-symmetrical current - load unbalance. Each of these adverse effects contribute to increasing the active power losses. The active power losses consist of the basic active power losses and the additional active power losses that are caused by the adverse effects. We tried to find out the adverse effects that influence the active power losses in three-phase cable power line and determined their size in a medium voltage grid. The adverse effects that are analyzed in this paper are load unbalance, displacement power factor of electrical energy consumption, and the higher harmonic orders. This paper is interesting for distribution system operators in relation to the financial costs reduction for covering the active power losses in electrical energy transmission [9].

Power Quality Indices

The term power quality is applied to a wide variety of electromagnetic phenomena on the power system. A large number of electronic devices in the Slovak Republic or around the world, do not meet the quality parameters, which leads to problems with the power quality. The term power quality can be also defined as any power problem manifested in voltage, current or frequency deviations that results in failure or misoperation of customer equipment [6, 10].

Voltage Unbalance (or imbalance) is defined by IEEE as the ratio of the negative or zero sequence component to the positive sequence component. In simple terms, it is a voltage variation in a power system in which the voltage magnitudes or the phase angle differences between them are not equal [3]. According to the standard EN 50160, the voltage unbalance is 100% of the 10-minute average mean square value of the negative-phase sequence component of the supply voltage must be within the range of 0% to 2% of positive-phase sequence component during one week under normal operating conditions [11, 12].

The displacement power factor does not belong to the qualitative parameter and it has an influence on power losses. Power factor is the ratio of the real power to the apparent power. There are two different ways to compute the power factor: displacement power factor and apparent power factor. Both give identical results for sinusoidal (non-distorted) voltage and current waveforms. The displacement power factor is based purely on the fundamental line frequency (50 or 60 Hz) content, while the apparent power factor includes harmonics in the computation. It is also defined as the ratio of current drawn that produces real work to the total current drawn from the source or supplier of the energy, such as the electric utility [13].

(1) $$\cos\varphi = \frac{P}{S} = \frac{P}{V \cdot I},$$

where cosφ is the displacement power factor; P is active power; and S is the apparent power.

The harmonic voltages are sinusoidal voltages having frequencies that are integer multiples of the frequency at which the supply system is designed to operate (usually 50 Hz/60 Hz). Periodically distorted waveforms can be decomposed into a sum of the fundamental frequency and the harmonics [4, 11, 14].

Total harmonic voltage distortion (THD_V) of a signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the power of all harmonic components to the power of the fundamental frequency. THD_V is used to characterize the power quality of electric power systems. Distortion factor is a closely related term and sometimes used as a substitute term. The standard EN 50 160 define, that THD_V shall not exceed 8 % or 5 % as a mean value over 10 minutes of one week 100 % of the time at all supply terminals. The limits for individual harmonics of voltage for LV, MV, HV (low voltage, medium voltage, high voltage) are defined in the standard EN 50 160 [11, 14, 15].

THD_V is determined as:

$$(2) \qquad THD_\mathrm{V} = \frac{\sqrt{\sum_{h=2}^{40} V_\mathrm{h}^2}}{V_1} \times 100\% \ \leq \ 5\,\%,$$

where h is harmonic order, V_h is the size of the corresponding order harmonic, and V_1 is the size of the fundamental harmonic.

Another power quality indices and their limited values are listed in the standard [15], or in [9]

Calculation of Power Losses in a MV Grid

The total power losses of MV three-phase system can be determined as:

$$(3)\ \Delta \boldsymbol{S}_\mathrm{C} = R_1 \cdot I_1^2 + R_2 \cdot I_2^2 + R_3 \cdot I_3^2 + \\ +j \cdot \begin{pmatrix} X_\mathrm{L11} \cdot I_1^2 + X_\mathrm{L22} \cdot I_2^2 + X_\mathrm{L33} \cdot I_3^2 \\ +X_\mathrm{L12} \cdot I_1 \cdot I_2 \cdot 2 \cdot \cos\varphi_\mathrm{I12} \\ +X_\mathrm{L13} \cdot I_1 \cdot I_3 \cdot 2 \cdot \cos\varphi_\mathrm{I13} \\ +X_\mathrm{L23} \cdot I_2 \cdot I_3 \cdot 2 \cdot \cos\varphi_\mathrm{I23} \end{pmatrix} = \Delta P_\mathrm{C} + j\Delta Q_\mathrm{C}.$$

It can be said that the inductive reactance of the power line contributes to the total power losses in medium voltage grid but does not participate in the active power losses. The losses can be influenced by the type of the conductor and the arrangement of conductors on the console, but also by changing the frequency [9].

According to Formula (3), the power losses can be divided to the active power losses and reactive power losses. For the total active power losses of medium voltage grid apply:

$$(4)\ \Delta P_\mathrm{C} = \Delta P_1 + \Delta P_2 + \Delta P_3 = R_1 \cdot I_1^2 + R_2 \cdot I_2^2 + R_3 \cdot I_3^2.$$

From the Formula (4), it can be said that the total active power losses depend only on the currents flowing through the resistance of the individual power line conductors. The magnitude of the active power losses depends on four following points [9]:

1. The magnitude of the individual conductors' resistance R.
2. The magnitude of the current flowing through the individual power line conductors – the load unbalance.
3. The current magnitude of the active and the reactive component – the displacement power factor.

The magnitude of RMS value of the current and its frequency – the higher harmonic orders.

Analysis of the Active Power Losses in Three-Phase Cable Power Lines in the Distribution Grid of 22 kV

This chapter is focused on the analysis of the active power losses in three-phase cable power lines in medium voltage grid. The active power losses were influenced by the adverse effects (load unbalance, displacement power factor, harmonics). Their influence was evaluated by created simulation model of the distribution grid of 22 kV in the simulation program Matlab-Simulink. In the simulation, the size of the active power losses was calculated by the active power at the start of power line minus the active power at the end of power line. It means that the difference was between the active power injected into the power line and the active power consumption [9].

The basic active power losses are the losses exist in every electric network, regardless of the occurrence of adverse effects. However, their magnitude depends on the voltage level of the distribution grid, and the type and length of the conductors and transformers that are used. These basic active power losses are increased by load unbalance, displacement power factor, and the harmonics [9].

The graphic dependencies of the active power losses in the three-phase cable power lines are shown in the following Figures 1, 2, and 3. The graphs show the dependence between the three-phase active power consumption P_{abc} and the active power losses ΔP for different types and lengths of NA2XS2Y cable conductors. Three types of cable conductor were used NA2XS2Y 95/16, NA2XS2Y 150/25, and NA2XS2Y 240/25. These cables are XLPE insulated single core cable, PE outer sheath, with aluminum conductors and screen of copper conductors. The XLPE means cross-linked polyethylene and the PE means the rigid polyethylene compound. In simulation, 3 single-core cables are laid in the ground into a triangle shape without gaps that are used for longer, fully loaded power lines.

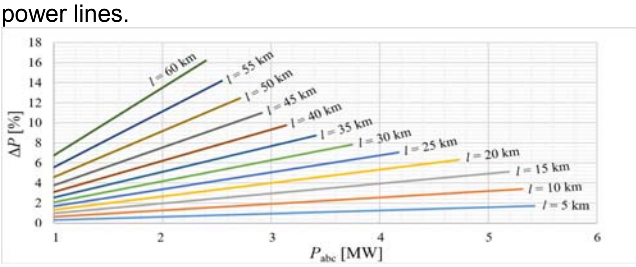

Fig.1. The active power losses for NA2XS2Y 95/16

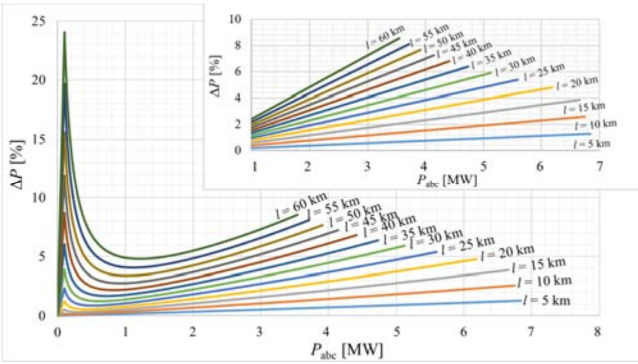

Fig.2. The active power losses for NA2XS2Y 150/25

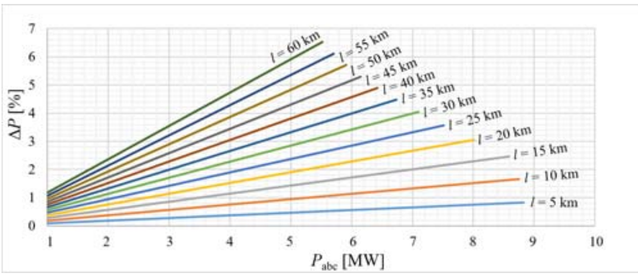

Fig.3. The active power losses for NA2XS2Y 240/25

From graph 2 can be seen high increase of the active power losses at relatively low load on a given cable line. This initial increase of the active power losses depends on the length of the cable power line. If the length of cable power line was increased, the initial increase of the active power losses has been increased too. This is happening due to the high capacity of the cable power lines, which is related to the flow of capacitive charging current in the no load power line. This current causes the active power losses in the power lines. In comparison to the low transmitted active power, the active power losses reach a higher percentage. This is not an error. For the clarity of graphs, the start of the horizontal axis was shifted to 1 MW for another graphs. The active power losses are calculated only in the area of higher transmitted active power. Reason for that was to remove the values that are significantly affecting the charging current.

From graphs 1-3 can be seen that if the three-phase active power consumption was increased, the active power losses on the cable power line were increased too. If the length of the cable power line is longer, then the active power losses for the corresponding three-phase active power consumption are also higher. Maximal value of the active power losses and the three-phase active power consumption is limited by the current loading capacity of the individual type of conductor and voltage values at the end of cable power line 12.7 kV ± 10 %. This current loading capacity is different for every conductor. For conductor NA2XS2Y 95/16 it is 254 A, for NA2XS2Y 150/25 it is 322 A, and for NA2XS2Y 240/25 it is 422 A. In simulation, the value of 60 % of the current loading capacity was used [9].

The load unbalance caused the different current flows in the power line and the different line voltages to drop. Every state of load unbalance caused an increase of the active power losses in the grid compared to the symmetrical state. Three scenarios were examined to show the increase of the active power losses [9]:

1. **Scenario:** the load change of phases A, B, and C (equally),
2. **Scenario:** the load change of phase A, phases B and C = 0,
3. **Scenario:** the load change of phases A and B (equally), phase C = 0.

The results of these three scenarios are graphs of the total active power losses on the three-phase active power consumption. These graphs for three types of cable conductors are shown in the following Figures 4, 5, 6 and 7, 8, 9. For the symmetrical state (scenario 1), the graph was the same, as shown in Figure 1, Figure 2, and Figure 3.

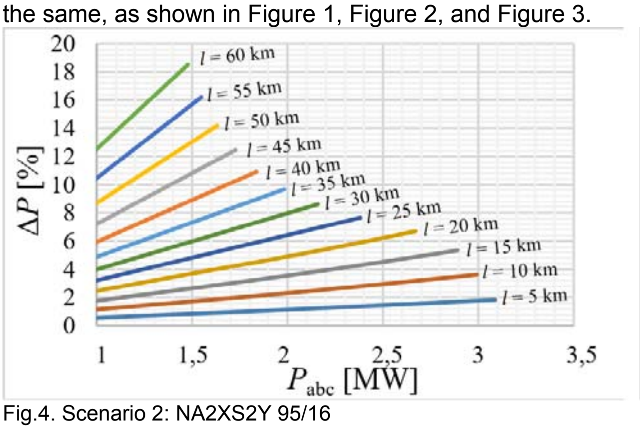

Fig.4. Scenario 2: NA2XS2Y 95/16

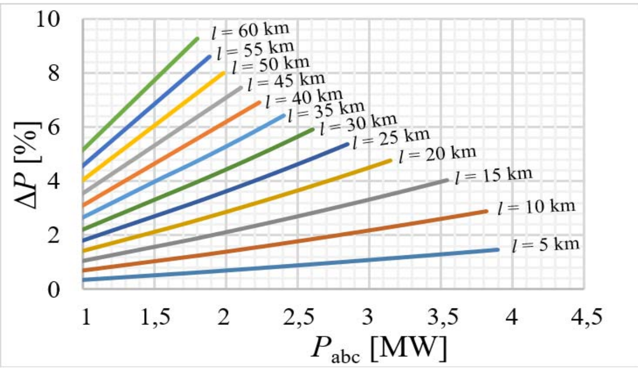

Fig.5. Scenario 2: NA2XS2Y 150/25

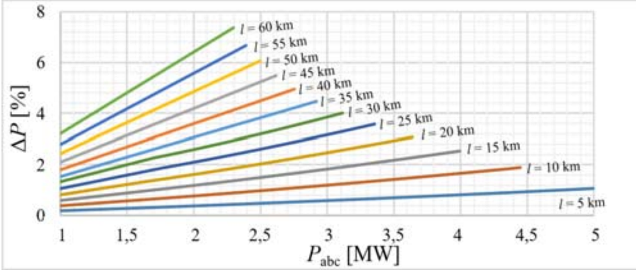

Fig.6. Scenario 2: NA2XS2Y 240/25

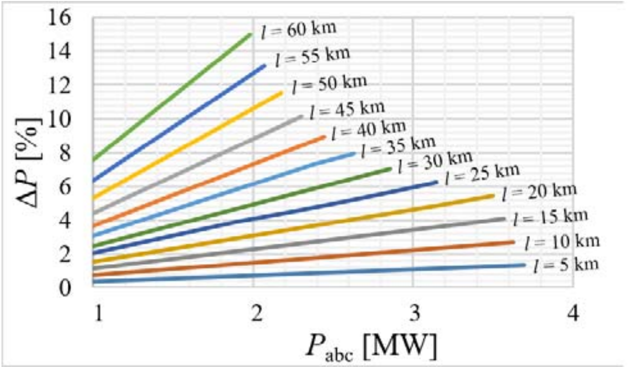

Fig.7. Scenario 2: NA2XS2Y 95/16

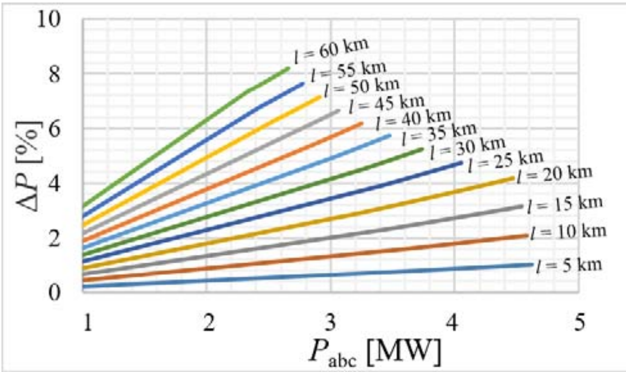

Fig.8. Scenario 2: NA2XS2Y 150/25

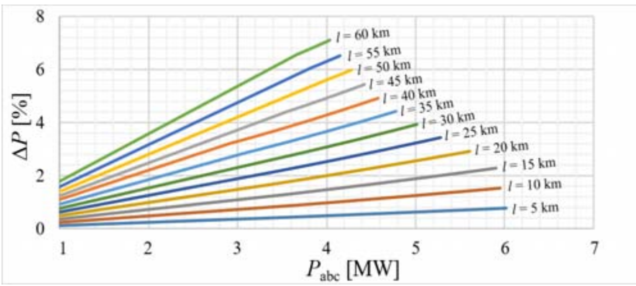

Fig.9. Scenario 2: NA2XS2Y 240/25

The graphic results of scenario 2 and scenario 3 are similar. The Figures 4-9 shows that the magnitude of the active power losses depends not only on the three-phase active power consumption, the type of cable, and the length of cable power line, but also on the individual phases load. We can say that if the length of the power line increases, the active power losses will also increase. If the three-phase active power consumption increases, the active power losses will also increase. If we compare these active power losses of scenarios 2, and 3 to the active power losses for the symmetric state, the three-phase active power consumption decreased by the same size for the active power losses. If we compare graphs of scenario 2 to graphs of scenario 3, the three-phase active power consumption was larger for the same active power losses. It was caused by the uniform load in two phases [9].

The increase of a reactive power in the grid was caused by aggravate displacement power factor. The total current in the grid, which causes the active power losses, consists of an active component and the reactive component. The reactive component of the current is necessary to minimize, because of that the spreading of the active power mainly in the power line and the active power losses were at minimum [9]. The increase of the active power losses is shown in Figures 10, 11, and 12.

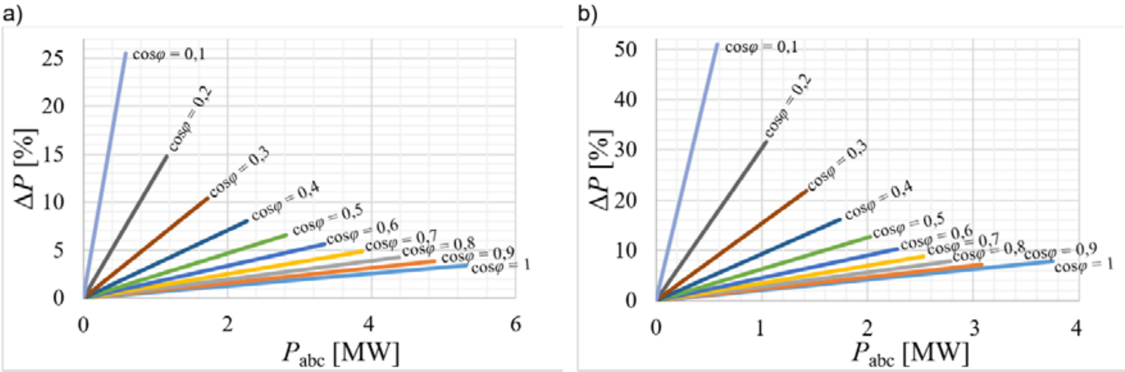

Fig.10. The active power losses for NA2XS2Y 95/16: a) the length of 10 km, b) the length of 30 km

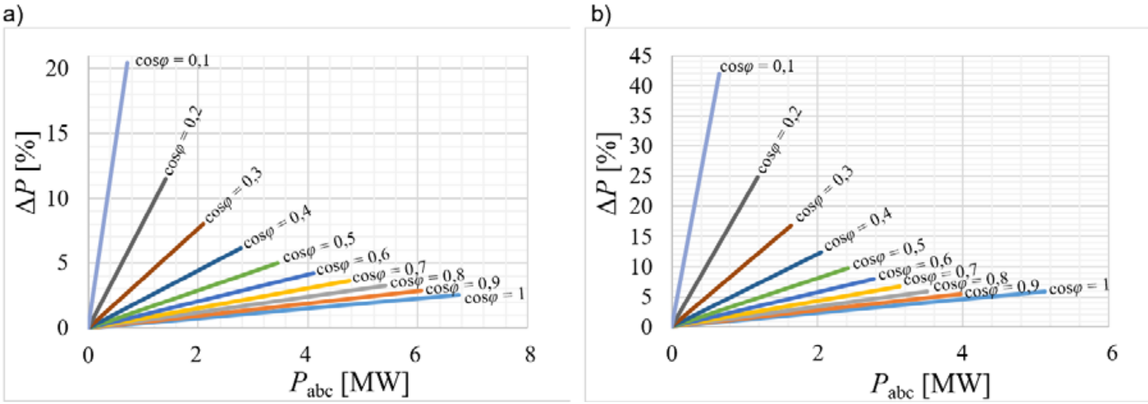

Fig.11. The active power losses for NA2XS2Y 150/25: a) the length of 10 km, b) the length of 30 km

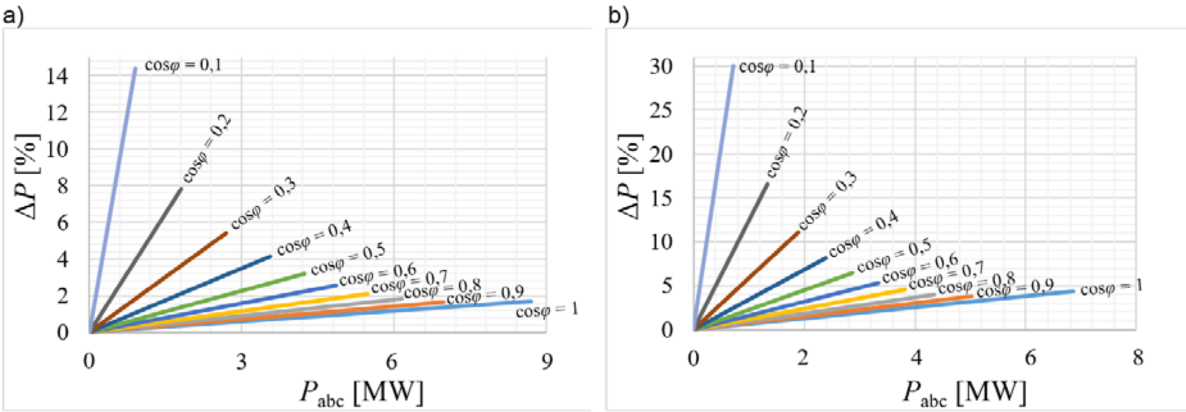

Fig.12. The active power losses for NA2XS2Y 240/25: a) the length of 10 km, b) the length of 30 km

From these figures, it mainly follows that [9]:

1. Three-phase active power consumption decreased due to the aggravate displacement power factor.
2. The active power losses in the three-phase cable power line increased due to the aggravate displacement power factor.
3. Three-phase active power consumption decreased due to the aggravate displacement power factor and increased in the length of the cable power line.
4. The active power losses in the cable power line increased due to the aggravate displacement power factor and increased in the length of the cable power line.
5. If the cable cross-section of the power line conductor is increased, the three-phase active power is increased at the given displacement power factor.
6. If the cable cross-section of the power line conductor is increased, the active power losses are decreased at the given displacement power factor.

The inharmonic grid current causes the active power losses, which correspond to the square of its RMS value. Active work only provides a real part of the fundamental harmonic current (in this case, if we have a non-linear appliance connected to the harmonic voltage source), currents of higher harmonic orders can be considered as the reactive component of the current of the fundamental harmonic.

The total active power losses in the three-phase power line were created not only from the current of the first harmonic, but also from the current of the individual higher harmonics [9].

Harmonic line loss refers to the network loss caused by harmonics. Harmonic power has no other benefit than creating the heat, but it is consumed in the form of heat in all aspects of the transmission process and in electrical equipment. Therefore, harmonic power is essentially the line loss-harmonic caused by harmonics. Therefore, the positive harmonic power increases the line loss of the power system. In addition to the increase of line loss, harmonics will also cause a decrease in the power factor, which indirectly leads to an increase in power loss. Reducing the harmonic line loss is due to the energy conservation and emission reduction of power grid companies [16].

In following Figures 13, 14, and 15 is shown the increase of active power losses caused by the higher harmonics. The higher harmonics does not create work, therefore the power flowing through the grid depends only on the fundamental harmonic. The value of current flowing through the power line and the active power losses increased by these higher harmonics are counted to the active power losses caused by the fundamental harmonic.

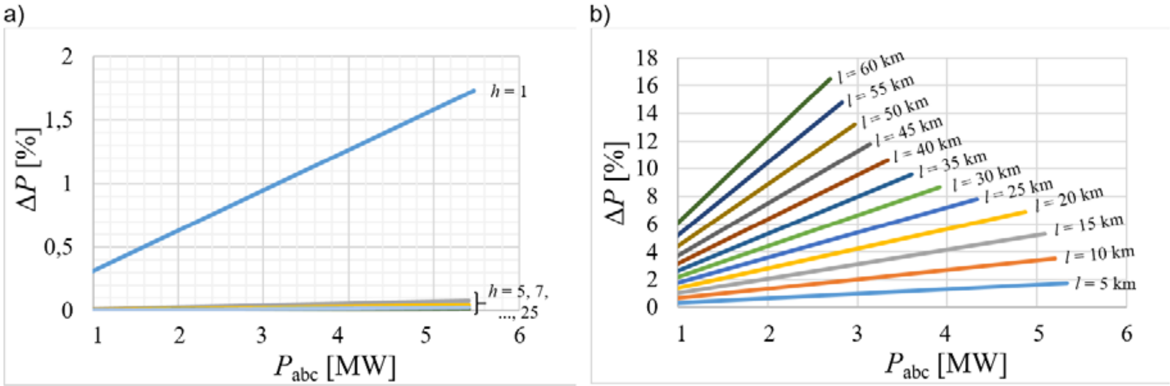

Fig.13. The active power losses for NA2XS2Y 95/16: a) the length of 5 km, b) the different length

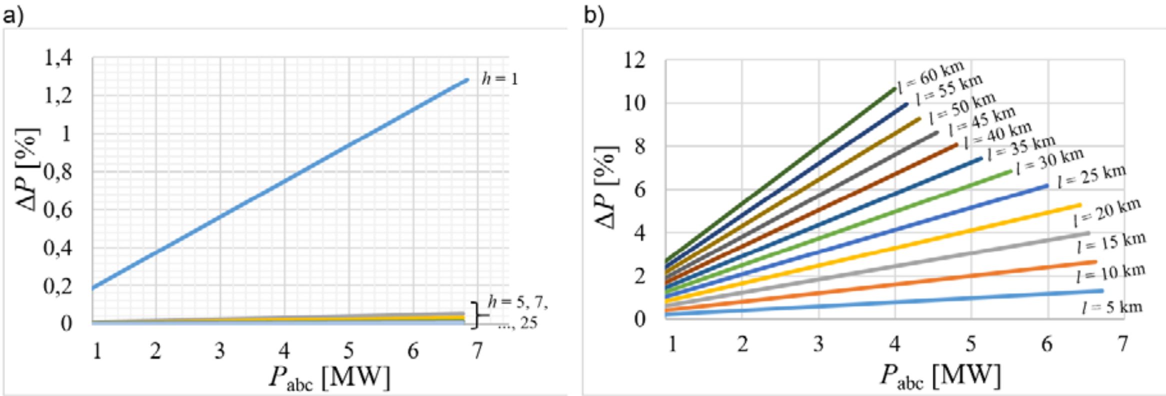

Fig.14. The active power losses for NA2XS2Y 150/25: a) the length of 5 km, b) the different length

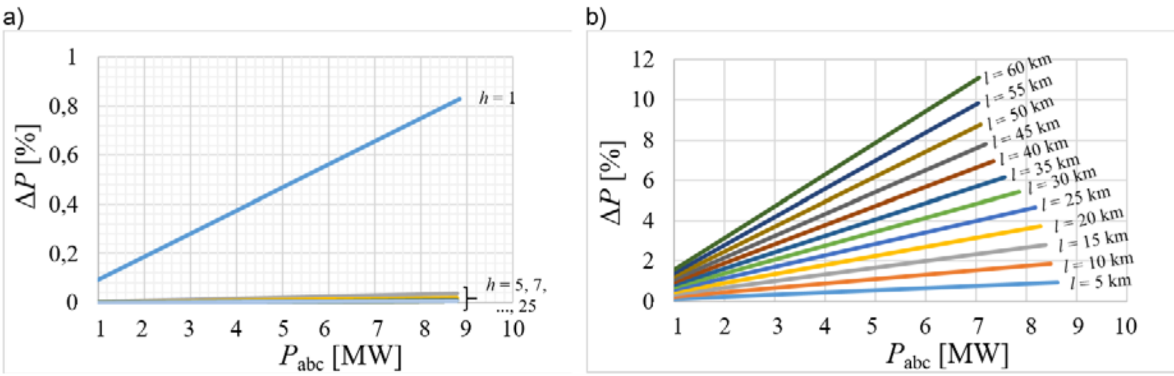

Fig.15. The active power losses for NA2XS2Y 240/25: a) the length of 5 km, b) the different length

Real Measurement of Different Locations

This chapter is focused on the analysis of individual transformer stations (TS) MV/LV measurement. These TS were located in different areas in the north of the Slovak Republic. TS were situated in the villages, shopping centers, industry, and housing estates. The summary measurement on low voltage side of transformers were performed in four villages and the other measured areas. Measurement of the individual outlets from TS was performed in two villages. The measurements were performed by the power quality analyzer BK-ELCOM ENA 330 and according to the currently valid standards. The power quality analyzers were set to save average, minimal and maximal values of the higher harmonic components *V*, *I*, *P*, *Q*, *S*, powers and energies, RMS half-period values.

In the following tables 1 - 4 are shown average values of the current load, displacement power factor, power factor (PF), etc. These values represent current state of the individual TS MV/LV.

Table 1. Average values of current load measured in TS MV/LV (villages)

	I_{avg} [A]									
	Location 1	**Location 2**	**Location 3**	**Location 4**			**Location 5**			
	16.5.2017 – 30.5 2017	**15.5.2017 – 29.5.2017**		**22.3.2017 - 5.4.2017**			**25.10.2016 – 3.11. 2016**			
	Σ	**Σ**	**Σ**	**v.1**	**v.2**	**v.3**	**Σ**	**v.1**	**v.2**	**v.3**
L1	97,0	39,0	74,7	24,3	24,2	23,5	101,0	26,8	55,8	21,6
L2	84,0	53,0	72,5	25,5	26,2	26,9	87,0	29,6	39,8	14,3
L3	97,0	61,0	79,9	16,9	27,1	29,4	107,0	26,6	48,5	32,4
N	36,0	24,0	31,0	11,9	10,9	10,7	42,0	13,1	20,4	11,0

Table 2. Average values of current load measured in TS MV/LV (shopping centers)

	I_{avg} [A]		
	Location 6 T1 **22.2.2019 – 8.3.2019**	**Location 6 T3** **22.2.2019 – 8.3.2019**	**Location 7** **15.11.2018 – 29.11.2018**
	Σ	**Σ**	**Σ**
L1	1134,0	505,0	640,0
L2	1021,0	464,0	578,0
L3	992,0	411,0	648,0
N	190,0	76,0	129,0

Table 3. Average values of current load measured in TS MV/LV (industry)

	I_{avg} [A]	
	Location 8 TR 1 **4.1.2019 – 18.1.2019**	**Location 8 TR 3** **4.1.2019 – 18.1.2019**
	Σ	**Σ**
L1	139,0	152,0
L2	146,0	150,0
L3	140,0	151,0
N	27,0	29,0

Table 4. Average values of current load measured in TS MV/LV (housing estates)

	I_{avg} [A]		
	Location 9 **19.10.2018 – 2.11.2018**	**Location 10** **19.10.2018 – 2.11.2018**	**Location 11** **19.10.2018 – 2.11.2018**
	Σ	**Σ**	**Σ**
L1	125,0	240,0	121,0
L2	112,0	226,0	139,0
L3	128,0	191,0	128,0
N	54,0	81,0	49,0

Table 5. Average values measured in TS MV/LV (villages)

	$\cos\varphi_{avg}$ [-]									
	Location 1	**Location 2**	**Location 3**	**Location 4**			**Location 5**			
	Σ	**Σ**	**Σ**	**v.1**	**v.2**	**v.3**	**Σ**	**v.1**	**v.2**	**v.3**
L1	0,968	0,962	0,971	0,966	0,946	0,988	0,969	0,937	0,982	0,973
L2	0,977	0,968	0,969	0,979	0,982	0,971	0,990	0,957	0,995	0,987
L3	0,987	0,973	0,973	0,991	0,974	0,960	0,979	0,963	0,998	0,984
	PF_{avg} [-]									
	Location 1	**Location 2**	**Location 3**	**Location 4**			**Location 5**			
	Σ	**Σ**	**Σ**	**v.1**	**v.2**	**v.3**	**Σ**	**v.1**	**v.2**	**v.3**
L1	0,955	0,955	0,957	0,959	0,945	0,977	0,960	0,927	0,975	0,960
L2	0,963	0,962	0,954	0,975	0,982	0,959	0,975	0,937	0,982	0,956
L3	0,973	0,971	0,961	0,964	0,965	0,954	0,971	0,942	0,981	0,973
	I -/+, I 0/+ [-]									
	Location 1	**Location 2**	**Location 3**	**Location 4**			**Location 5**			
	Σ	**Σ**	**Σ**	**v.1**	**v.2**	**v.3**	**Σ**	**v.1**	**v.2**	**v.3**
I -/+	14,00	18,09	15,17	23,51	17,74	16,68	15,08	16,20	18,36	30,46
I 0/+	13,48	16,34	13,45	24,58	15,72	15,73	13,49	17,26	17,87	18,54

Table 6. Average values measured in TS MV/LV (shopping centers)

	$\cos\varphi_{avg}$ [-]			PF_{avg} [-]			I -/+, I 0/+ [-]			
	Location 6 T1	**Location 6 T3**	**Location 7**	**Location 6 T1**	**Location 6 T3**	**Location 7**		**Location 6 T1**	**Location 6 T3**	**Location 7**
	Σ	**Σ**	**Σ**	**Σ**	**Σ**	**Σ**		**Σ**	**Σ**	**Σ**
L1	0,999	0,981	0,999	0,991	0,953	0,991	**I -/+**	7,527	23,468	6,654
L2	0,999	0,980	0,999	0,990	0,945	0,986	**I 0/+**	10,334	7,356	13,429
L3	0,999	0,974	1,000	0,993	0,928	0,991				

Table 7. Average values measured in TS MV/LV (industry)

$\cos\varphi_{avg}$ [-]			PF_{avg} [-]			*I* -/+, *I* 0/+ [-]		
	Location 8 TR 1	**Location 8 TR 3**		**Location 8 TR 1**	**Location 8 TR 3**		**Location 8 TR 1**	**Location8 TR 3**
	Σ	**Σ**		**Σ**	**Σ**		**Σ**	**Σ**
L1	0,985	0,980	**L1**	0,982	0,978	***I* -/+**	5,464	5,467
L2	0,982	0,977	**L2**	0,981	0,975	***I* 0/+**	6,883	7,439
L3	0,980	0,972	**L3**	0,978	0,969			

Table 8. Average values measured in TS MV/LV (housing estates)

$\cos\varphi_{avg}$ [-]				PF_{avg} [-]			*I* -/+, *I* 0/+ [-]			
	Loc. 9	**Loc. 10**	**Loc. 11**	**Loc. 9**	**Loc. 10**	**Loc. 11**		**Loc. 9**	**Loc. 10**	**Loc. 11**
	Σ	**Σ**	**Σ**	**Σ**	**Σ**	**Σ**		**Σ**	**Σ**	**Σ**
L1	0,967	0,978	0,999	0,951	0,969	0,974	***I* -/+**	13,388	8,896	14,846
L2	0,960	0,986	0,999	0,942	0,978	0,975	***I* 0/+**	15,636	13,840	17,365
L3	0,976	0,971	0,999	0,958	0,964	0,973				

In the tables, the values from two-weeks measurement with date of measurement are shown. These data were used to obtain an overview of the size and load character in each TS MV/LV. The worst load unbalance was achieved in shopping center (Location 6) and the housing estate (Location 10). The best displacement power factor was achieved in the areas, where the compensation devices are installed (Location 6, Location 8). Aggravated displacement power factor was present in housing estates and villages (there are no compensation devices).

Another monitored parameters were the power factor, the ratio of the negative-sequence current component to the positive-sequence current component and the ratio of the zero-sequence current component to the positive-sequence current component. These are shown in the tables 5 – 8. Based on the measurement from the analyzed TS MV/LV, it can be generally assumed that the deterioration of these indicators occurs mainly in low-load TS MV/LV outlets. The higher the load was measured the displacement power factor and the unbalance were more favorable. These mentioned indicators have a great impact on the active power losses in the LV grids and also on the active power losses in the MV grids. The deterioration of these indicators occurs precisely, when the grid or TS outlet is low-loaded, what means that the active power losses are already minimal.

The most loaded TS MV/LV in the individual areas were chosen for the simulation inputs. From the villages, it is Location 5, from shopping centers Location 6 T1, from industry Location 8 TR3 and from the housing estates Location 10. The simulation was performed for one type of cable conductor NA2XS2Y 95/16 with lengths of 5 km to 25 km. Created simulation model of distribution grid is shown in figure 16.

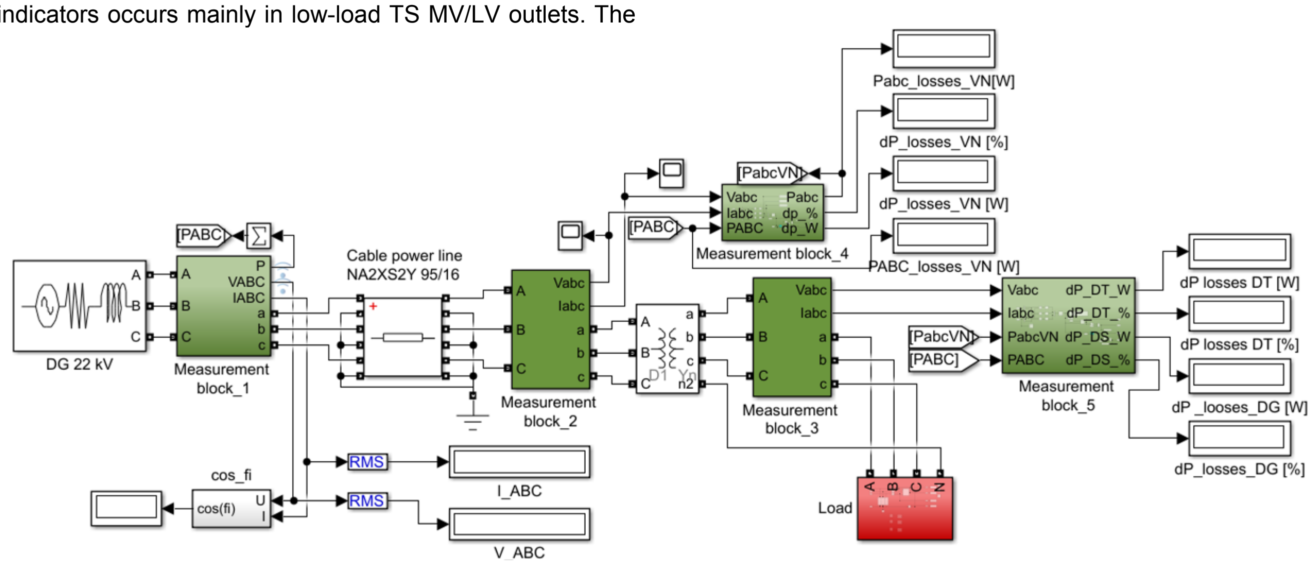

Fig.16. Simulation model of distribution grid

RMS value of 50 A current was chosen on each phase, which represents about 30 % of load in real operation. Therefore, it was necessary to aggregate the load blocks of the individual areas on the LV side. For Location 6, it was an aggregation of 2 consumption sites. Location 8 represent 5 consumption sites, Location 5 represent 18 consumption sites and Location 10 represent 10 consumption sites. The aggregation was performed due to low-load of MV side from LV side, when the impact on the active power losses in MV grid was negligible. The second reason was that the real measurement represents only one consumption point. The number of consumption points is higher at greater distances.

In the following tables 9 – 12 are shown percentual values of the active power losses for the lengths of 5 km to 25 km.

Table 9. Results of the active power losses from simulation for area Loacation 6

Cable	Length of power line *l* [km]	5	10	15	20	25
NA2XS2Y 95/16	Basic losses ΔP_b [%]	0,5058	1,041	1,656	2,397	3,311
	Unbalance ΔP_{unb} [%]	0,5282	1,087	1,724	2,485	3,412
	cosφ ΔP_{pf} [%]	0,5071	1,048	1,671	2,424	3,352
	Harmonics ΔP_{har} [%]	0,5062	1,043	1,663	2,408	3,334

Table 10. Results of the active power losses from simulation for area Loacation 8

Cable	Length of power line *l* [km]	5	10	15	20	25
NA2XS2Y 95/16	Basic losses ΔP_b [%]	0,746	1,182	1,813	2,648	3,549
	Unbalance ΔP_{unb} [%]	0,766	1,227	1,92	2,72	3,664
	cosφ ΔP_{pf} [%]	0,757	1,185	1,858	2,672	3,589
	Harmonics ΔP_{har} [%]	0,75	1,183	1,818	2,655	3,557

Table 11. Results of the active power losses from simulation for area Loacation 5

Cable	Length of power line *l* [km]	5	10	15	20	25
NA2XS2Y 95/16	Basic losses ΔP_b [%]	0,5627	1,148	1,796	2,552	3,457
	Unbalance ΔP_{unb} [%]	0,5844	1,196	1,878	2,671	3,614
	cosφ ΔP_{pf} [%]	0,5642	1,158	1,828	2,617	3,564
	Harmonics ΔP_{har} [%]	0,563	1,152	1,801	2,579	3,483

Table 12. Results of the active power losses from simulation for area Loacation 10

Cable	Length of power line *l* [km]	5	10	15	20	25
NA2XS2Y 95/16	Basic losses ΔP_b [%]	0,5587	1,146	1,779	2,507	3,417
	Unbalance ΔP_{unb} [%]	0,623	1,268	1,977	2,79	3,744
	cosφ ΔP_{pf} [%]	0,5718	1,149	1,806	2,584	3,577
	Harmonics ΔP_{har} [%]	0,559	1,148	1,802	2,523	3,452

It can be seen from previous tables that the displacement power factor and harmonics do not cause a significant increase in the basic active power losses. We can say that the active power losses are at the level of the basic active power losses, because their value increases in the second or the third decimal place. It is caused by the measured areas of achieved power factor values of the fundamental frequency in the range of 0.977 to 0.999 inductive character. The impact on the active power losses the impact of harmonics is negligible, because the harmonics of order 3 causes losses in zero conductor. The active power losses on MV side are slightly increased by the unbalance on LV side. Every adverse effect would have a greater impact on the active power losses on LV side. This is due to the distribution transformer construction (Dyn).

In figures 17 – 20 are shown the graphical dependencies of percentual active power losses from the length of the cable line.

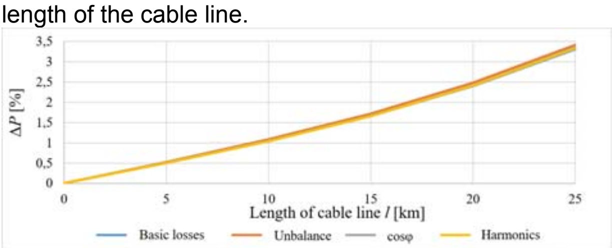

Fig.17. Active power losses on MV side for Location 6

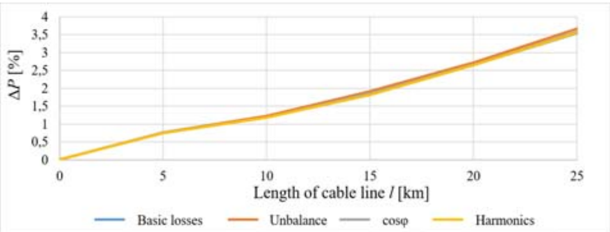

Fig.18. Active power losses on MV side for Location 8

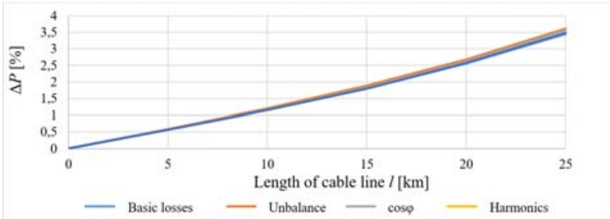

Fig.19. Active power losses on MV side for Location 5

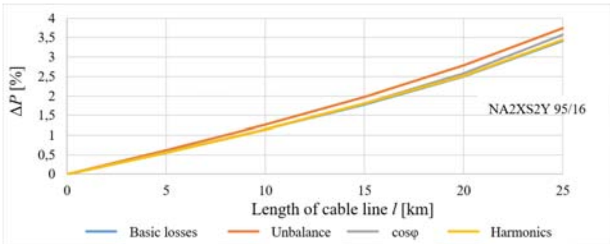

Fig.20. Active power losses on MV side for Location 10

As can be seen from previous figures, the influence of the power quality indices has not big impact on the active power losses in the MV grid. We can say that due to the increase of the cable line length, the active power losses are increased almost linearly. This is due to the electrical parameters of cable line (type and construction of the cable).

The worst power quality factor that affect the active power losses in the MV grid from real measurements was the load unbalance. Therefore, in Table 13 is shown an overview of the active power losses due to load unbalance for a one year and financial losses at the power price of 40 eur/ MW. The overview of the active power losses was calculated for the length of 15 km. We can say that the biggest financial lost for the distribution system operators is the housing estate Location 10. The smallest is the shopping center, Location 6. For the other two power quality factors, the active power losses for one year were not calculated, because their impact on the MV grid was minimal.

Table 13. Overview of active power losses and their impact on finance for the length of 15 km

Area	Type of Conductor	Load [kW]	Active Power Losses in Medium Voltage Grid				Informative Price of Power Energy
			ΔP [%]	ΔP [MW/hour]	ΔP [MW/year]	ΔP_{ADD} [MW/year]	40.00 EUR/MW
Location 6	NA2XS2Y 95/16	1751.23	1.724	0.0302	264.474	19.209	768.37
Location 8	NA2XS2Y 95/16	1989.77	1.92	0.0382	334.664	30.310	1212.41
Location 5	NA2XS2Y 95/16	1924.46	1.878	0.0361	316.598	25.506	1020.24
Location 10	NA2XS2Y 95/16	1967.72	1.977	0.0389	340.780	51.319	2052.79

Conclusion

This paper deals with the determination of the active power losses in three-phase cable power line in the MV grid. The active power losses were caused by the load unbalance, the displacement power factor and the harmonics. These three power quality factors are considered to be the adverse effects that are increasing the basic active power losses in every distribution grid. The load unbalance can be considered for the worst adverse effect from the real measurements. The displacement power factor and the harmonics did not contribute to the significant increase of the basic active power losses. The increase of the basic active power losses can represent a big active power loss and then a big financial loss for distribution system operators. From this reason, it is necessary to pay a big attention to the active power losses in distribution grids. On the other hand, it is necessary to find appropriate solutions to reduce or minimize the given three power quality factors.

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