ANALYSIS OF VOLTAGE QUALITY PARAMETERS IN MV DISTRIBUTION GRID

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ABSTRACT

This paper describes the impact of operation of big customers on voltage quality parameters in medium voltage distribution grids. The survey is based on the evaluation of 45 voltage quality measurements which were carried out in 15 different delivery points of other customers. These 45 measurements were made in years 2014, 2015 and 2016 (15 measurements a year) and were evaluated according to standard EN 50160. The impact on voltage variations and other voltage quality parameters was analysed.

INTRODUCTION

The supply territory of the company E.ON Distribution in the Czech Republic (run by the company E.ON Czech Republic) accounts for approximately 1.5 million customers when approximately 6000 customers are supplied from medium voltage (MV) level. Problems with flicker, voltage variations and harmonic voltage were detected in low voltage (LV) distribution grids but the analysis from the MV level is not available. The electricity market liberalisation brings considerable pressure to introduce penalties for insufficient voltage quality (VQ) parameters. In case of poor voltage quality, these penalties should be of the electricity rebate payment nature. The analysis of VQ parameters in the distribution grid is necessary for definition of interface between the customer and distribution network operator (DNO) from view of responsibility for poor VQ. The 22 kV voltage level is the level for connection of bigger customers to the distribution grid and it is necessary to know the conditions in it. This paper brings a detailed analysis of VQ parameters in this MV grid.

DESCRIPTION OF MEASURED GRIDS

Fifteen customers connected to the MV distribution grid are measured for many years when VQ measurement is temporary with the duration of one week according to the standard EN 50160 [1]. The measured period during the year is chosen accidentally with respect to possibility of the DNO. The MV customers have own substation with the own transformer 22/0.4 kV. Voltage quality measurement has to be done in the delivery point of the customer so that voltage quality is measured on the output of the voltage instrument transformer (VT) 22/0.1 kV. This instrument transformer is a part of MV switchboard and it is in the possession of customer. The distance between the customer and the supply HV/MV substation can be different – see the Fig. 1.

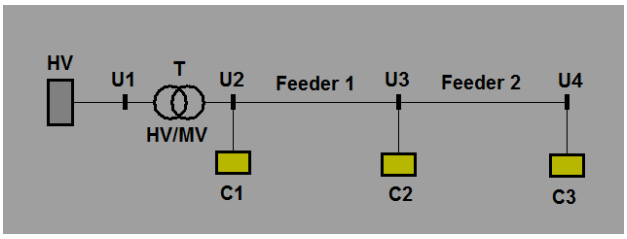

Fig. 1 General block diagram of grid (C1, C2, C3 – measured customers connected to the MV grid)

For comparison of the distance from HV/MV substation we used calculation of short circuit power in delivery point of customers – see the Fig. 2.

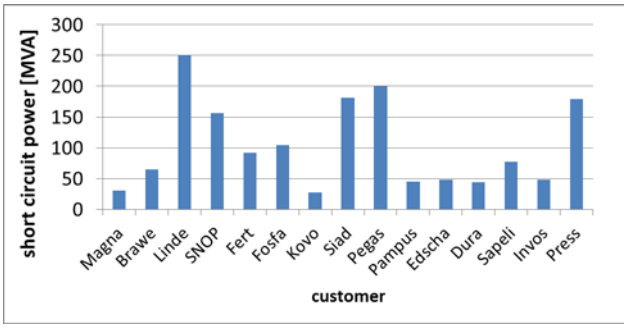

Fig. 2 Short circuit power in delivery points of measured customers

Reference value of short circuit power (short circuit impedance) does not exist for MV distribution grids in contrast to LV distribution grids [2]. The experience of DNO shows that the distance about 30 km between the customer and supply HV/MV substation is too long when this distance is equivalent to approximately 30 MVA of short circuit power (in case of ACSR conductor). According to author's more than 10 year experience in the field of voltage quality, the reference short circuit power of 50 MVA is proposed as the reference value. This reference value of short circuit power should be used as the guideline for decision about responsibility for poor VQ. It is the question, when the DNO and when the

customer is responsible for poor voltage quality. This topic is permanently actual.

REQUIREMENTS OF THE EN 50160 STANDARD

Voltage variations

All the MV measurements were evaluated according to the standard EN 50160 [1]. Under normal operating conditions excluding the periods with interruptions, supply voltage variations should not exceed ± 10% of the nominal voltage Un. A test method for medium voltage level (under normal operating conditions) follows these rules/requirements [1]:

- During each period of one week at least 99% of the 10 min mean r.m.s. values of the supply voltage shall be below the upper limit of Un + 10%; and
- During each period of one week at least 99% of the 10 min mean r.m.s. values of the supply voltage shall be above the lower limit of Un - 10%; and
- All 10 min r.m.s. values of the supply voltage shall be within the range of Un + 15%/-15%

Also when one 10 min mean r.m.s. value of the supply voltage exceeds during the week the limit Un + 15% (115% Un) or when more than 1% of 10 min mean r.m.s. values xceed during the week the limit Un + 10% (110% Un), it results in overvoltage and voltage quality (voltage variations) will not comply with the requirements of the standard EN 50160.

Flicker

Under normal operating conditions, during each period of one week the long term flicker severity P_{lt} caused by voltage fluctuation should be less than or equal to 1 for 95 % of the time.

Harmonic voltage

Under normal operating conditions, during each period of one week, 95 % of the 10 min mean r.m.s. values of each individual harmonic voltage shall be less than or equal to the values given in [1] when the limit value for the 3rd voltage harmonic is 5%, for the 5th voltage harmonic is 6%, for the 7th voltage harmonic is 5% and for the 15th voltage harmonic is 0.5% of nominal voltage (only the most important harmonic voltages were selected). Moreover, the THD of the supply voltage (including all harmonics up to the order 40) shall be less than or equal to 8 %.

Unbalance

Under normal operating conditions, during each period of one week, 95 % of the 10 min mean r.m.s. values of the negative phase sequence component (fundamental) of the supply voltage shall be within the range 0 % to 2 % of the positive phase sequence component (fundamental).

Frequency

The nominal frequency of the supply voltage shall be 50 Hz but frequency is set from the transmission system so it is not evaluated in this paper because of its small role for LV systems with synchronous connection. It is important to evaluate frequency in LV systems with no synchronous connection when the power source operates in an island mode [3].

EVALUATION OF VQ MEASUREMENTS

Voltage variations

In the Fig. 3 and Fig. 4 you can see the evaluation of maximal/minimal 10 min mean r.m.s. values of supply voltage (V99%max and V99%min) in 15 delivery points of MV customers.

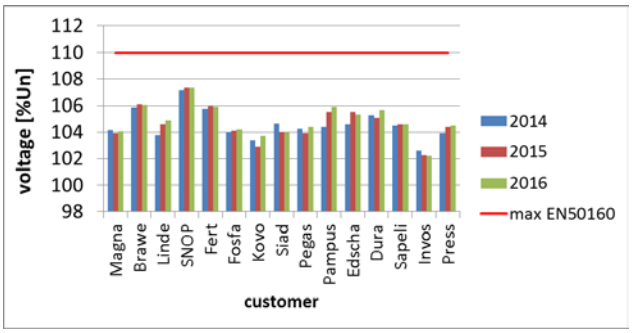

Fig. 3 Evaluation of maximal voltage variations (99% percentile), comparison to the upper voltage limit

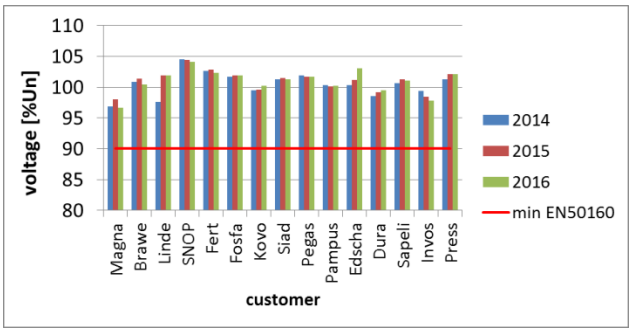

Fig. 4 Evaluation of minimal voltage variations (99% percentile), comparison to the lower voltage limit

The Fig. 3 and Fig. 4 show conforming voltage variations in all grids. Maximal voltage reaches the value 107.3 % Un in case of the customer Snop (see the Fig. 3) and minimal voltage reaches the value 96.6 % Un in case of the customer Magna (see the Fig. 4).

Voltage difference dU between maximal and minimal voltage values during the measurement was evaluated too – see the Fig. 5. The voltage difference reaches the value 7.4% Un in case of the customer Magna which is supplied by means of ACSR conductor with the length of approximately 30 km (distance from HV/MV supply substation). Voltage difference depends not only on short circuit power (which is very low in case of the customer

Magna) in the delivery point but also on load of grid. Load was not evaluated but we recommend taking account of load in future survey.

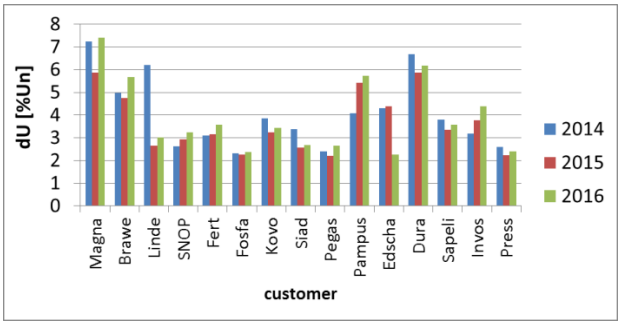

Fig. 5 Voltage difference between maximal (99% percentile) and minimal (99% percentile) voltage values

Flicker

In the Fig. 6 and Fig. 7 you can see the evaluation of long-term flicker (Plt) and short-term flicker (Pst) in delivery points of MV customers. The flicker limit is exceeded in case of the customer Magna (both Plt and Pst) and Kovo (both Plt and Pst in 2014, only Plt in 2015). The algorithm for evaluation of long-term flicker can be negatively influenced by voltage dips caused by faults occurring in the public network [4]. If no faults during the measurement period occur, then long-term flicker values do not differ from short-term flicker values (for example the customer Magna). If faults during the measurement period occur, then long-term flicker values are higher than short-term flicker values (for example the customer Kovo in 2015). Thus we recommend evaluating both long-term flicker and short-term flicker together. Short-term flicker has higher information value than long-term flicker although the EN 50160 defines limit value only for long-term flicker.

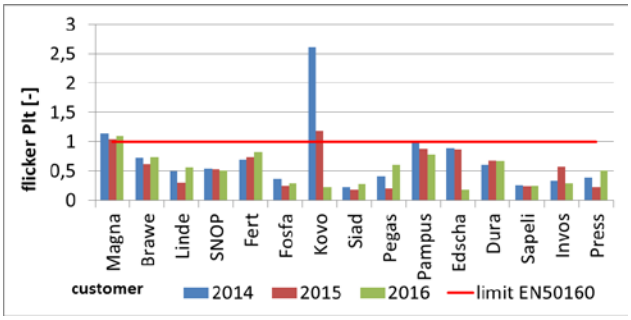

Fig. 6 Evaluation of flicker Plt

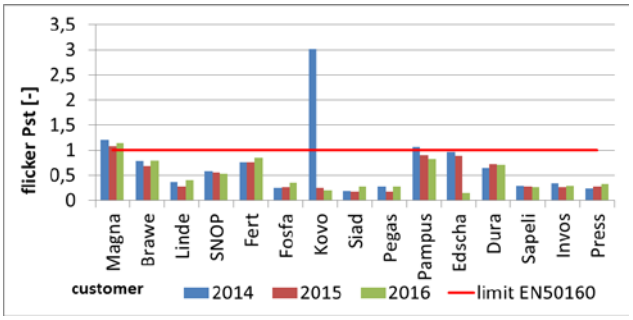

Fig. 7 Evaluation of flicker Pst

Harmonic voltage and THD

The Fig. 8 shows no problem with the 3rd voltage harmonic, the Fig. 9 shows no problem with the 5th voltage harmonic (with the exception of the customer Pegas in 2016), the Fig. 10 shows no problem with the 7th voltage harmonic and the Fig. 11 shows no problem with the 15th harmonic voltage.

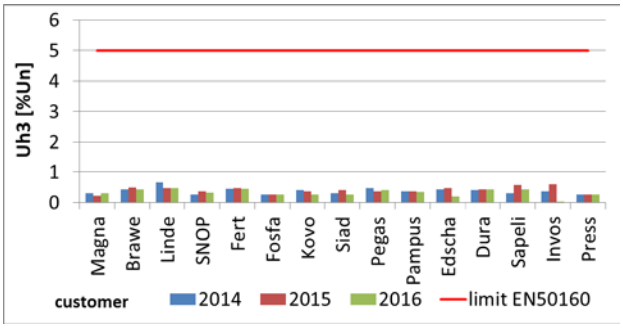

Fig. 8 Evaluation of the 3rd voltage harmonic

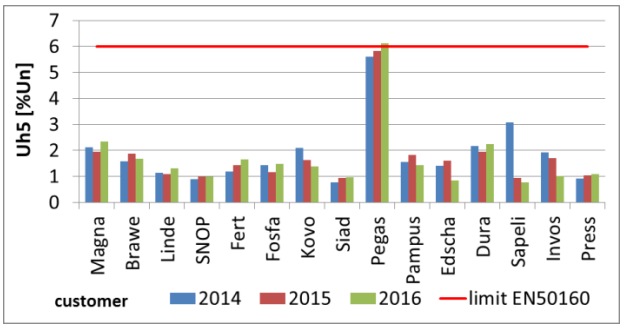

Fig. 9 Evaluation of the 5th voltage harmonic

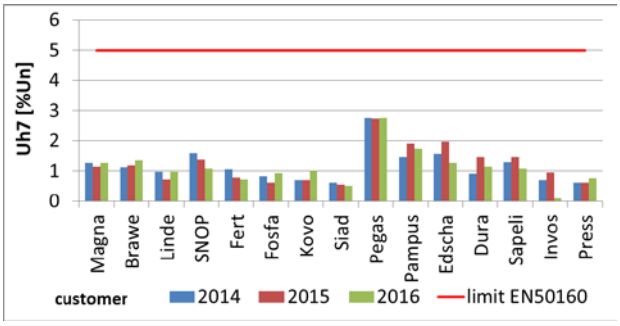

Fig. 10 Evaluation of the 7th voltage harmonic

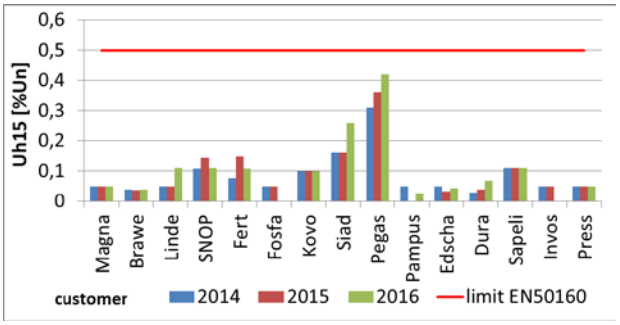

Fig. 11 Evaluation of the 15th voltage harmonic

The Fig. 12 shows no problem with total harmonic distortion (THD) in medium voltage grid.

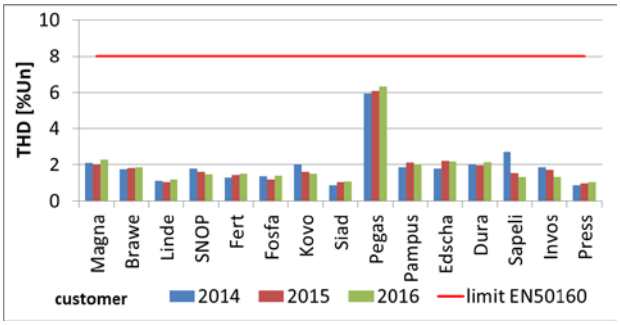

Fig. 12 Evaluation of total harmonic distortion THD

Voltage unbalance

The Fig. 13 shows the evaluation of voltage unbalance (95% percentile). There was evaluated no problem with voltage unbalance in MV grids.

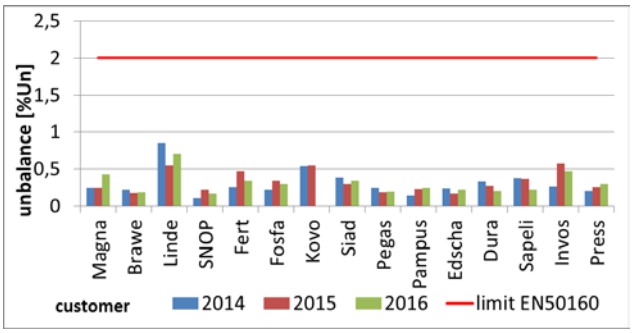

Fig. 13 Evaluation of voltage unbalance

CUSTOMER MAGNA – DETAILED ANALYSIS

Flicker level in delivery point of the customer Magna exceeds the limit. Flicker is produced by operation of new forging presses which were put into operation in 2012. The customer Magna was informed about the problem of flicker because it was proved that flicker was caused by the customer's operation. The flicker intensity depends on the current intensity. The customer did not believe the DNO that the flicker was produced by its operations and so it was decided that the university should perform an independent assessment of the cause of the flicker.

Assessment of the cause of flicker

Experts from the technical university in Ostrava made independent VQ measurements and they discovered the cause of the flicker. The customer operates two forging presses and the university experts compared the flicker level in two states (see Tab. 1.). In the first state both the forging presses were operated and the flicker level reached the value of 1.16 on the MV side. In the second state both the forging presses were out of operation and the flicker level reached the value of 0.63 on the MV side and so the dependence of the flicker on the operation of the forging presses was proved.

State of the operation	Flicker Plt [-]
Forging presses are in operation	1.16
Forging presses out of operation	0.63

Tab. 1 Flicker on the MV level in different states of the operation

After this independent study the customer accepted that he was responsible for the flicker in the MV grid and he proposed a remedy. This remedy is based on adjusting the forging presses. It is possible to remedy the situation from the side of the DNO too. The DNO suggested building a new HV/MV substation near the customer so that the short circuit power should increase and the flicker level should decrease. This solution would take many years due to the justification of construction of a new high-voltage distribution feeder.

Remedy from the side of the customer

The forging presses operate with a definite reserve for performing the pressing. This reserve was 100% because of defective work. With the reduction of this reserve the current value should decrease. A decrease in the current value should reduce the flicker level. The customer proposed reducing the reserve R from R=100% to R=75% and R=60%. The defective work has to be evaluated. Analysis of measurement show that the RMS peak of the current is approximately 700 A for R=100%, approximately 540 A for R=75% and approximately 400 A for R=60%. The amplitude of the voltage changes depends on the amplitude of the current peak and the flicker level depends on the amplitude of voltage changes. Thus the flicker level decreased because of smaller voltage changes, but not enough. After the adjustment of both the forging presses to R=60%, the flicker level reached the value approximately of 1.1 and the number of defective products did not increase. Voltage quality in the MV distribution grid does not comply with the requirements of the EN 50160 standard because of flicker but Magna has no other way to solve the problem apart from halting production. Fortunately, no complaints regarding the flicker were received.

Remedy from the side of DNO

It is possible to remedy the situation from the side of the DNO too. The DNO is planning to build a new HV/MV substation near the customer so that the short circuit power should grow and the flicker level should drop. The expected value of the short circuit power after the building of the new HV/MV substation is approximately S_k"=130MVA. So the flicker level should drop below the limit according to the EN 50160 standard – see the Tab. 2. The investment costs for building the new HV/MV substation, including a supply HV feeder, are approximately one million EUR. This solution will take many years due to the hearing of construction of a new high-voltage distribution feeder.

Way of supply	Current MV feeder	New HV/MV substation
S_k" [MVA]	30	130
Flicker P_{lt} [-]	1.1	0.25

Tab. 2 Short circuit power in the delivery point of Magna

Voltage dips

It is interesting that no complaints regarding the flicker were received, although the flicker level exceeds the value P_{lt}=1. But complaints about voltage dips were received and one of the complaining customers is Magna. This customer is supplied by a long MV feeder (approximately 30 km) and so many voltage dips occur. Voltage dips can cause the same effect as long-term interruption by customers with hard automation. The EN 50160 standard defines no limits for voltage dips but the analysis of historical data can enter the algorithm of the prediction methods used [5]. Voltage dips are typically caused by faults occurring in the public network, so in the case of an outside MV feeder faults and voltage dips mainly occur in summer as a result of the impact of the weather (windstorms). A short voltage interruption on the primary side (on the MV level) results in a short voltage interruption on the secondary side of the MV/LV transformer. Short voltage interruptions of MV feeders with failure are transmitted into other networks as voltage dips [6].

CONCLUSION

The paper brings a view on voltage quality in MV distribution grids and deals in detail with the problem of flicker in case of the customer Magna. It is a problem when the VQ in the MV distribution grid does not comply with the requirements of the EN 50160 standard because VQ is influenced by many other customers. The question is who is responsible for poor VQ. A simple method based on the correlation of the flicker and current was described in this paper. The remedy does not always have to be expensive from the point of view of the customer but sometimes it might be not sufficiently efficient. In this study the DNO is going to build a new HV/MV substation but it takes about three years. No other affordable solution is possible apart from halting the production but the DNO has limited tools to realise it. It can therefore be stated that in the case of customers who consume high power with a considerable dynamic shape of loading that causes flicker outside the permitted tolerance (and where production optimisation has already taken place, for instance, by the distribution of manufacturing over time in order to prevent the simultaneous running of those appliances that contribute to the flicker the most), the most suitable way to reduce the flicker is by increasing the short circuit power, for instance, by building a new transformer station, etc. For this type of power take-off, the authors recommend performing a connectivity study before connecting the industrial plant to the network, in which the elaborator should take into account a future increase in the reserved power input over the period of approximately the following 10 years.

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