Flicker Caused by Operation of Industrial Technology

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Abstract. *There are more and more electrical devices operating in industrial plants which impact negatively on the distribution network. The EN 50160 standard defines the voltage characteristics of electricity supplied by the public distribution system and it is a problem for a distribution network operator when the voltage quality in the distribution network does not comply with the requirements of the EN 50160 standard because of complaints about voltage quality. Such a complaint is justified and the distribution network operator has to pay a penalty and has to remedy the situation. This paper describes a problem of flicker in the medium-voltage distribution grid when the flicker is produced by one customer operating a forging press. The remedies from the side of the distribution network operator and the customer with the aim of reducing the flicker level in the grid are described.*

Keywords

EN 50160 standard, flicker, voltage dip, voltage quality.

1. 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. Most customers are connected to a Low-Voltage (LV) distribution grid and six thousand customers are connected to a Medium-Voltage (MV) distribution grid, with the nominal voltage of the MV grid in the Czech Republic being 22 kV. Every year the Distribution Network Operator (DNO) E.ON monitors Voltage Quality (VQ) at the delivery points of some important customers supplied from the MV distribution grid. A general circuit diagram is shown in Fig. 1. One of the measured customers is a customer called Magna. This customer has its own MV substation (see Fig. 2) with its own 22/0.4 kV transformers T1 and T2. Voltage quality measurement has to be performed at the delivery point of the customer (node U3 in Fig. 1) so that the voltage quality is measured at the output of the instrument transformer 22/0.1 kV. This instrument transformer is a part of the MV switchboard and it is in the possession of the customer.

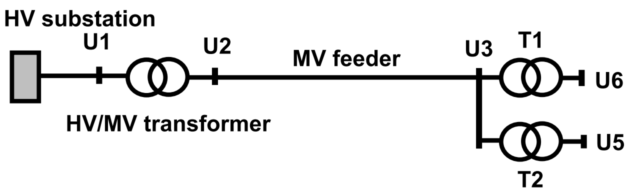

Fig. 1: General circuit diagram of connection of customer to MV grid.

2. Voltage Quality and the EN 50160 Standard

2.1. Supply Voltage Variations

Under normal operating conditions, excluding periods with interruptions, supply voltage variations should not exceed ± 10 % of the declared voltage U_c and the

Fig. 2: MW switchboard of the customer Magna (node U3 according to Fig. 1).

test method according to the standard [1] is the following:

- at least 99 % of the 10-min mean r.m.s. values of the supply voltage must be below the upper limits of +10 %,
- at least 99 % of the 10-min mean r.m.s. values of the supply voltage must be above the lower limits of -10 % given in 5.2.2.1,
- none of the 10-min mean r.m.s. values of the supply voltage must be outside the limits of ± 15 % of U_c.

2.2. Flicker Severity

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 [6].

3. Evaluation of VQ Measurements

3.1. Supply Voltage Variations

Figure 3 and Fig. 4 show that voltage variations comply with the EN 50160 standard. Small differences between 100 % and 99 % values were evaluated. The maximal 10-min mean values reach the value of 106.7 % U_n (Fig. 4, year 2013) and the minimal values reach the value of 95.8 % U_n (Fig. 4, year 2012).

3.2. Flicker Severity

Figure 5 shows the flicker increasing from 2012. The limit P_{lt}=1 is exceeded and the problem has to be solved.

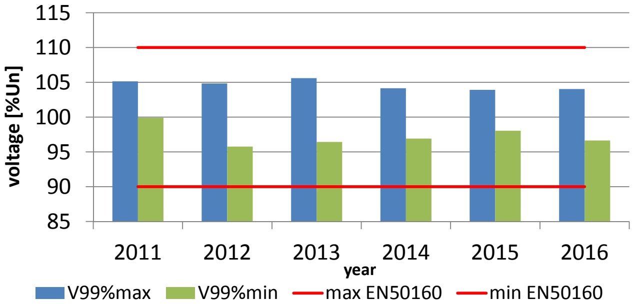

Fig. 3: Evaluation of voltage variations (99 % percentile).

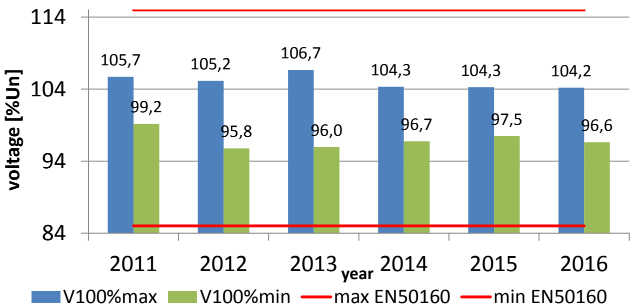

Fig. 4: Evaluation of voltage variations (100 % percentile).

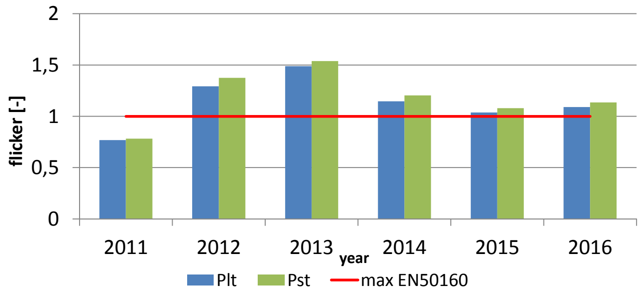

Fig. 5: Evaluation of short-term severity (P_{st}) and long-term severity (P_{lt}).

4. Responsibility for Poor Voltage Quality

4.1. Source of Flicker

Flicker is produced by the operation of new forging presses (see Fig. 7 and Fig. 8) which were put into operation in 2012.

To find the source of flicker it is necessary to measure and evaluate the current and flicker together. When the flicker waveform corresponds to the current waveform (see Fig. 8), the flicker is produced by the customer being measured.

Fig. 6: Forging press (Magna).

Fig. 7: Belt feeder of sheet steel for the forging press.

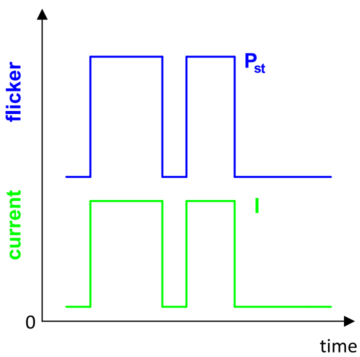

Fig. 8: Dependence of flicker on current.

4.2. Study if Forging Presses Connectable

A study of the VQ was made before the connecting of the forging presses because it was supposed beforehand that the operation of these forging presses would influence the VQ negatively. The author of this study did not recommend the connection of the forging presses because of flicker when a flicker level above the value 1 was calculated [2].

4.3. Call from the Side of the DNO

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 – see Fig. 8. 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.

4.4. Assessment of the Cause of the Flicker Performed by the University

Experts from the Technical University of Ostrava made independent VQ measurements and 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.

Tab. 1: Flicker on the MV level in different states of the customer's operations.

State of the operation	Flicker P_{lt} (-)
Forging presses are in operation	1.16
Forging presses out of operation	0.63

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.

5. 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.

Figure 9 shows that the RMS peak of the current is approximately 700 A if R=100 %. Figure 10 shows that the RMS peak of the current is approximately 540 A if R=75 %. Figure 11 shows that the RMS peak of the current is approximately 400 A if R=60 %. A summary evaluation is given in Tab. 2.

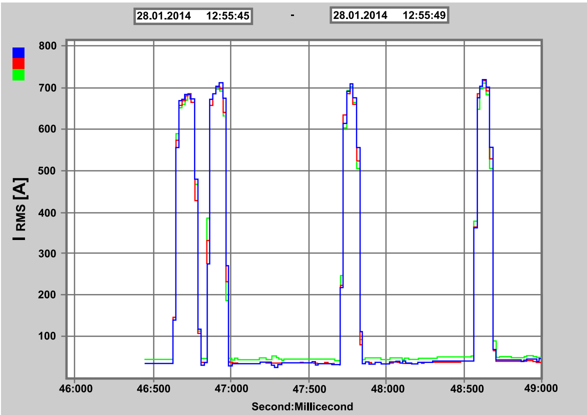

Fig. 9: RMS peak of current, forging press set to R=100 %.

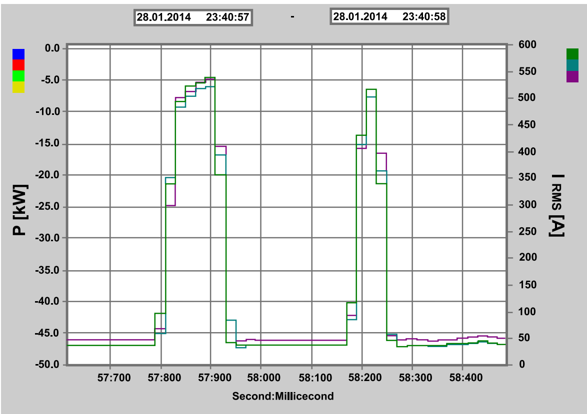

Fig. 10: RMS peak of current, forging press set to R=75 %.

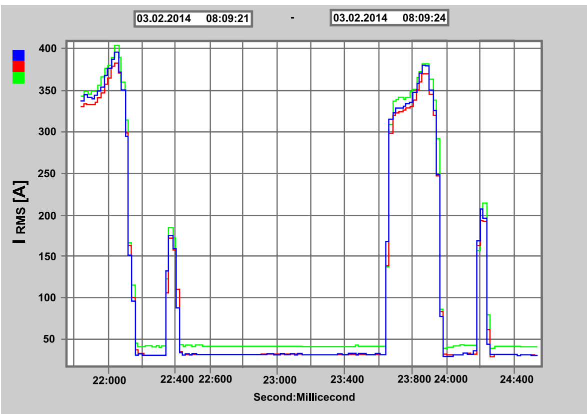

Fig. 11: RMS peak of current, forging press set to R=65 %.

Tab. 2: Current peak in dependency of reserve R.

R of the forging press (%)	Current peak (A)
100	700
75	540
60	400

The size of the voltage changes depends on the size of the current peak (see Fig. 12) and the flicker level depends on the size of the voltage changes. Thus the flicker level decreased because of the changes to a lower voltage, but not enough. After the adjustment of both the forging presses to R=60 %, the flicker level reached the value approximately of 1.1 (see Fig. 5, years 2014, 2015 and 2016) and the number of rejects did not increase. The 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.

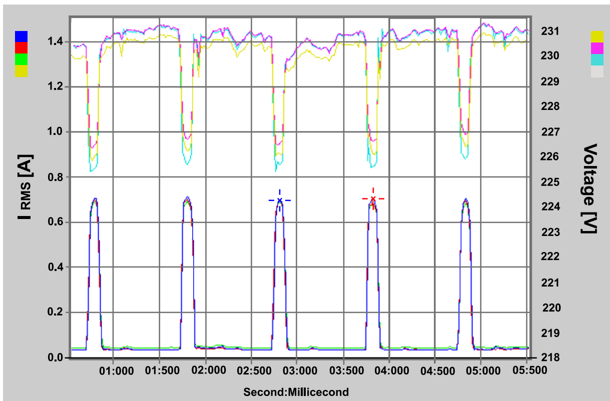

Fig. 12: RMS peak of current (lower curve) and voltage changes (upper curve) on the low-voltage level.

6. Remedy from the Side of the DNO

It is possible to remedy the situation from the side of the DNO too. The DNO plans 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''=130 MVA. So the flicker level should drop below the limit according to the EN 50160 standard – see Tab. 3. 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 justification of construction of a new high-voltage distribution feeder [5].

Tab. 3: Short circuit power at the delivery point of Magna.

Way of supply	Current MV feeder	New HV/MV substation
S_k'' (MVA)	30	130
Flicker P_{lt} (-)	1.1	0.25

7. Flicker Propagation

Many other customers are influenced by the operation of the forging presses, or, more precisely, the flicker level P_{lt}=1 can be expected to be exceeded at the delivery point of more customers. The highest flicker values should be experienced by customers in the vicinity of Magna. The flicker level should decrease with an increase in the distance from the HV/MV transformer. This theoretical assumption was verified by practical measurement. It was measured at two points of the MV grid. The first measurement was made at the delivery point of Magna (node U4 according to Fig. 13) and the second at the delivery point of another customer (node U4 according to Fig. 13). The distance between the customer C1 and the HV/MV transformer is less than the distance between the customer C2 and the HV/MV transformer. Both the measurements were performed at the same time and the duration of these measurements are one week. The measurements were evaluated according to the EN 50160 standard when the short circuit power was calculated at the delivery points of both the customers.

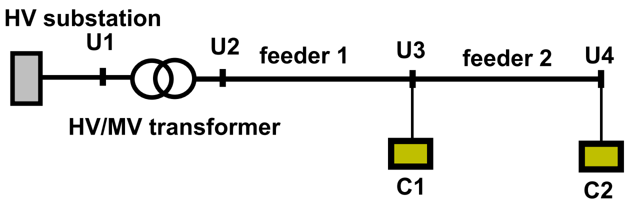

Fig. 13: General circuit diagram of connection of customers to MV grid.

Tab. 4: Short circuit power and measured values of flicker P_{lt} at the delivery point of the customers.

Customer	S_k'' (-)	Flicker P_{lt} (-)
C1	40.4	0.93
C2	29.2	1.32

Table 4 shows the values of satisfactory flicker level at the delivery point of the customer C1 when the flicker value is less than P_{lt}=1. If the flicker level at the delivery point of the customer C2 is known, the flicker level at the delivery point of the customer C1 should theoretically reach the value:

$$P_{lt}(\mathrm{C1}) = P_{lt}(\mathrm{C2}) \cdot \frac{S_k''(\mathrm{C2})}{S_k''(\mathrm{C1})} = 1.32 \cdot \frac{29.2}{40.4} = 0.95. \quad (1)$$

The calculated flicker level P_{lt}=0.95 at the delivery point of the customer C1 accords with the measured value P_{lt}=0.93 and thus the theoretical assumption regarding the flicker propagation was confirmed.

8. Problems of 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 (see Fig. 14). 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 [3]. 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 [4].

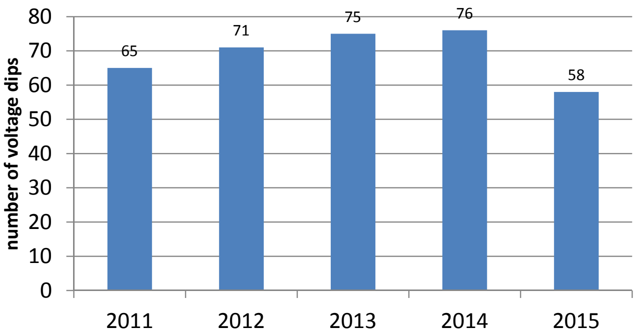

Fig. 14: Number of recorded voltage dips at the delivery point of Magna.

9. Conclusion

Experts from the Technical University of Ostrava, in cooperation with colleagues from the company E.ON, performed new monitoring measurement in November 2015 (on the MV level at the delivery point of the customer Magna). Figure 5 shows the evaluation according to the EN 50160 standard. The flicker level P_{lt}=1 was exceeded but so far no complaints have been received. The next VQ measurement will be performed in March 2017.

It is a problem when the VQ in the MV distribution grid does not comply with the requirements of the EN

50160 standard because it influences 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 not be 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. Magna has to produce and the flicker causes the firm no problems but Magna is sensitive to voltage dips. DNO has no positive experience of the operation of dynamic compensation because the compensation is too slow when a response time of no more than 5 ms is needed and the use of compensation balance is too expensive.

It can therefore be stated that in the case of customers who consume high power with a considerable dynamic course 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.

Acknowledgment

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