INFLUENCE ZONES AND DISTURBANCE LEVELS IN LV AND MV DISTRIBUTION NETWORK IN RESULT OF SUPPLY OF INDUSTRIAL WELDER LINES EQUIPPED WITH POWER CONDITIONER

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INTRODUCTION

The quality of electric energy depends not only on aspects concerning its generation, but also on its use, distribution and delivery. Each of the mentioned areas has a significant influence on power quality and as well on customers' satisfaction. It is obvious, that expectations of different users regarding the power quality are different and depend on requirements of equipment used by them. Usually bad quality of the delivered electric energy cause problems connected with equipment malfunctions or difficulties with supply voltage variations.

Usually the normal and disturbing loads are supplied from the same lines of the distribution network. Fast voltage variations in the distribution network are mainly caused by dynamic loads variations and switching processes. Repeating voltage variations cause the light flickering and are the source of difficulties connected with this phenomenon.

In Poland, according to electric energy legislation, the distribution system operators are responsible for maintaining the warranted service levels [1, 2]. They should apply price discounts for the customers in cases for power delivery with worsened technical parameters and put on disturbing entities some technical and economical sanctions basing on conditions included in their use of system contract.

The reactions on the effect of light flickering are subjective and depend on the cause of flickering and on the time it lasts. One of the major problems of maintaining the good quality of electric energy distribution is the effective limitation of negative influences of disturbing loads on the common network. This requires first of all the application of appropriate measurement techniques able to obtain the precise and undistorted data concerning the loads supplied by the distribution networks.

In case the admissible values of supply voltage distortions are exceeded, the undertaking of attempts to limit the negative influences of disturbing loads on the distribution network are necessary. In the extreme situations, even the contract interruption with a disturbing load can be considered.

PROBLEM IDENTIFICATION

In one town supplied by the Power Distribution Company situated in western Poland, steadily grew the number of complaints of inhabitants caused by the bad power quality mainly the light flickering. The problems concerned the users of network having approx. 10 thousand customers being supplied from one section of 15 kV busbar of HV substation. This 110/15 kV substation was composed of two transformers with rated power of 16 MVA each supplying residential, industrial and commercial loads by two separate MV busbar sections.

The diagram of the considered HV substation is shown in fig. 1. The operator of distribution system had to undertake actions aimed to detect, identify and propose solutions for correcting the bad power quality.

IDENTIFICATION OF INFLUENCE ZONES

The burdensome effects of voltage fluctuations and flicker reported by the customers concerned the 0,4 kV network supplied from one section (No 2) of the substation. The preliminary measurements, carried out by the distribution company’s employees followed by the investigating analysis enabled to identify the probable source of disturbances. Actions undertaken next were aimed to identify precisely the source of these disturbances and to work out the method to minimize the observed difficulties. The PQ parameters measurement points were chosen to obtain precise results and to qualify the influence zones of the disturbing load and long-term measurements were undertaken in 110/15 kV substation, MV network and LV distribution network being supplied from 15/0,4 kV transformers.

It was established that the accumulated source of disturbance was a manufacturing plant assembling heaters and using welder lines, which within the technology process consume surge unsymmetrical currents. The factory was supplied by radial cable connection 2,2 km long from a substation presented in fig. 1 characterized by rather low short-circuit
power of $S_{sc}=480$ MVA at the level of 110 kV.
The factory substation included 9 transformers with rated power $S_n=1.6$ MVA and 2 transformers of $S_n=2.5$ MVA. These transformers supply two technology lines, other supplementary receivers and two SIPCON P systems. The disturbing current injection takes place in three transformers of rated power 1.6 MVA.

With regard to observed large dynamics of voltage and loads variations high-frequency temporary values of disturbance signals were recorded. The measurements of PQ parameters were carried out in the substation at the 15 kV side and as well in 0.4 kV network in 15/0.4 kV substations on different sites of the supplied area. The monitoring measurement points were placed also placed in different MV lines in the close neighborhood of the substation and with distances of 4-10 km from it.

**Disturbances source identification**

Within the technology process in the factory the electric welders are used to assemble the heaters’ elements. In normal conditions 2 welder lines are working. On each line there are several two-phase and three-phase multipoint welders rated at $56 – 80$ kVA each. Welding of the elements is synchronized in the way to limit surges at the power supply points of the distribution network.

The welder lines consume surge currents with values of $2-4.8$ kA, with repetition periods $\Delta T=0.41-1.33$ s and the impulse width of $\Delta t=0.26-0.40$ s. Fig. 2 presents the current surges consumed by welders supplied from one transformer (Tr5-1.6 MVA or Tr6-2.5 MVA).

![Fig. 2. Typical fluctuations of rms input current of welders at the level of 0.4 kV](image)

Impulse input currents of the welders are unsymmetrical. Voltage fluctuations related to them are shown in fig.3. Higher values of consumed current correspond to higher voltage drops and vice versa. The values of correlation factors between current inputs and voltages at the 0.4 kV transformer side-supplying welders are shown in table 1.

**Table 1: Values of correlation factors between the welders’**

<table>
<thead>
<tr>
<th>Measured values</th>
<th>UL1-IL1</th>
<th>UL2-IL2</th>
<th>UL3-IL3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation factors</td>
<td>-0.982</td>
<td>-0.983</td>
<td>-0.981</td>
</tr>
</tbody>
</table>

![Fig.3. Correlated voltage fluctuations caused by the welders’ currents on the 15/0.4 kV transformer busbars in the factory](image)

According to the PN-EN 50160 [3] long-term flicker severity level is described by the following formulae

$$P_{st} = \frac{1}{T} \sum_{n=1}^{12} P_{st}^n$$

(1)

where: $P_{st}$ – short-term flicker severity level

During normal working conditions of welder lines the values of $P_{st}$ are illustrated in fig 4 and are rather high.

![Fig.4. Values of Plt coefficient at the busbars supplying the welders (minimal values are related to weekends)](image)

**Measurements in substations on MV busbars**

The measurements and analyses were aiming to find the correlation of voltage fluctuations in the substation and the load variations causing them. With regard to large dynamics of voltage and loads variations it was necessary to record also the temporary values of registered signals. The mean values in 1 and 10-minutes intervals of phase active power and reactive power consumed by the factory measured at 15 kV busbars are in the range of $P_{mean}=500-900$ kW/phase for active power and not larger than $Q_{mean}=-150$ up to $+100$ kvar for reactive power (capacitive and inductive power simultaneously). Maximum values of the 3-phase active power $P_{3f}$ are presented in figure 5. Recorded maximum values of phase reactive powers in 1-minute mean intervals showed larger dynamics and were varying in the range $Q_{max}=0.8$ to $1$ Mvar_ind and $Q_{min}=-0.6$ to $+1$ Mvar_cap (fig.6).
Fig.5. Maximum values of active power $P_{3f}$ consumed by the heaters’ factory from 15 kV busbars in a substation in 1-minute mean intervals.

Fig.6. Maximum and minimum values of reactive power $Q_{L1}$ in 1-minute mean intervals, in LV substation side of the heaters’ factory.

These unsymmetrical reactive powers are looped in the substation transformer windings. During the measurements conducted in MV side of 110/MV substation in the bay supplying the heaters’ factory the similar frequency shape of current impulses and of RMS voltage values fluctuations were recorded. Voltage sags corresponding to the current surges are shown registered at this place are shown in the figure 7. Voltage swells with amplitudes similar to voltage sags are accompanied by the falling slopes of current pulses.

The repeated every $\Delta T = 0.4 - 1.3$ sec. jumps of line-to-neutral voltage RMS values, being within the range of 90-540 V, were noticed on 15 kV busbars in result of the pulse currents consumed by the factory. The negative correlation factors of these voltage sags and current pulses were in the range of 0,546 to 0,738.

The $Plt$ values exceeded 1,0 during the factory working hours (fig.8). During the weekends the factors values reached $Plt=Pst=0.2$. Start-up of the welders lines caused the $Plt$ factor values increase up to values higher than 1,0.

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**Measurements in LV network**

Measurements were carried out in several 15/0,4 kV substations at LV level. The numerous temporary variations of current, voltages and power were registered to verify whether the recommendations of the standard PN-EN 50160 are fulfilled. The recorded fluctuations of RMS voltage were identical with the waveforms recorded in MV section of the considered HV substation concerning the frequency which was forced by the factory’s load. The input current of loads supplied from the 15/0,4 kV substation’s was varying in proportion to supplying voltage variations. Example of recorded variations of RMS voltage values in one of the 15/0,4 kV substations is shown on fig.9.
The depth of changes of line-to-neutral voltage, which in MV network reached 540 V, caused changes of $\Delta U=4.1-6.9$ V in LV network. These sudden voltage changes resulted in exceeding the admissible values of voltage fluctuations (Plt $\leq 2.4$, in fig.10 and table 2) and important difficulties in normal use of the receivers being supplied from the same MV section from which the heaters’ factory was supplied.

During the days off (weekends) the values of flicker indicator were maintained at the level of Plt=0.2.

Table 2: Plt value in one of 15/0.4 kV station

<table>
<thead>
<tr>
<th>95% - value</th>
<th>Max Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VL1</td>
<td>2.02</td>
</tr>
<tr>
<td>VL1</td>
<td>2.37</td>
</tr>
</tbody>
</table>

MEANS FOR PQ IMPROVEMENT

In order to damp the disturbances injected to the distribution network the Power Conditioner System SIPCON P is applied in the factory, which consists of two sets of active filters connected to 15 kV network via 3 transformers rated at $Sn=1.6$ MVA and a passive LC filter rated at 4.4 Mvar. The investigation basing on measurements results showed the direct influence of impulse loads on voltage quality in LV and MV distribution networks. They measurements conducted enabled to correlate voltage fluctuations in LV distribution network with varying loads and finally to identify a source of the disturbances. They also indicated rather limited (poor) operational effectiveness of the installed power conditioner SIPCON P system. In order to reduce the flicker, an installation of additional 110/15kV transformer supplying separately the factory on high voltage level was proposed as well as the strengthening of the network at the 110kV side was advised (up to $Ssc=1000$ MVA).

CONCLUSIONS

The research and measurements enabled to identify the source of disturbances and to estimate the level of disturbing influence of the heaters factory’s loads on voltage fluctuations in LV and MV distribution networks. It was shown that surge-like power and current fluctuations introduced by welders are characterized by repeated periods of duration $\Delta T=0.41-1.33$ s and impulse widths of duration $\Delta t=0.26-0.40$s and cause the exceeding of admissible levels of flicker indicator factors Pst and Plt.

The measured values of factors Plt and Pst laid between 1.19-3.25 with 17.78 as the upper value. They exceeded 95% of the admissible values within 65-90% of the measurement period duration. Allowable values were significantly exceeded during the factory working hours.

SIPCON P Power Conditioner System applied in the factory operates with limited effectiveness concerning the dumping of dynamic variations of power consumed by the welders. The two times reduction of voltage fluctuations in the analyzed area can be achieved by the installation of an additional HV transformer supplying exclusively heaters’ factory and by the increase of short-circuit power at the level of 110kV up to $Ssc = 1000$ MVA.

REFERENCES

