Standards-Based Investigation of Voltage Dips and Voltage Imbalances in an Organized Industrial Zone

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***Abstract*—The measurement, monitoring and evaluation of power quality have a great importance for avoiding grid- and device-based problems in the stages of generation, transmission, distribution and consumption of electrical energy. For this purpose, several standards have been set up in order to minimize the effects distorting the power quality of power systems in our country and in the world. In case of investigating these standards, it is mined that voltage dips and voltage imbalances are among the significant technical quality parameters for power systems. In this study, the voltage dips and voltage imbalances occurred in the phase-to-phase effective voltages of a medium-voltage transformer located in an organized industrial zone have been analyzed according to the standards. The number of higher voltage dips and the ratios of excessive voltage imbalances are uncovered and many reasonable assessments are made for them.**

Keywords—Power systems, power quality, standards, voltage dip, voltage imbalance

I. INTRODUCTION

The need for electrical energy is increasing day by day and the characteristics of loads connected to the power systems are changing rapidly. This condition makes power quality and energy efficiency more important for the power systems [1]. In this respect, voltage dips and voltage imbalances occurred in the power systems are considered as the leading problems in terms of the power quality [2]. The voltage dip is the short-term decrease of the supply voltage effective value at nominal frequency [3]. The main reasons of voltage dips are the malfunctions in the transmission and distribution systems, network failures, overloads, and the starting of large powerful motors and their short circuits [4]. On the other hand, the voltage imbalance is the condition in a polyphase system in which the effective values of line voltages and/or the phase angles between consecutive line voltages are not all equal [5]. The main reason of voltage imbalances is the feeding of single-phase loads, whose power is not equal. In addition, power system failures, overhead lines that are not being transposed and voltage regulators that are not working properly cause to the voltage imbalances [5, 6].

In the literature, the concept of power quality and the factors affecting power quality have been identified and many studies have been conducted on voltage dips and voltage imbalances among these factors. *Chang et. al.* reduced the severity of the voltage sag by tuning the transformer impedances and relay settings [7]. *Bozalakov et. al.* studied the positive-sequence control strategy and the three-phase damping control strategy for the voltage support during voltage dips and the depth of the voltage dip was minimized [8]. *Saeed et. al.* described the performance of dynamic voltage restorers under different voltage sags based on the different types of short-circuit faults and the pre-sag compensation method achieved the effective correction of voltage sags [9]. *Zhang et. al.* analyzed the characteristic of voltage dips with the special emphasis on symmetrical components and a generalized voltage dip model was built taking into account the load connections, transformer types and fault types [10]. *Oliveira et. al.* investigated the discrepancies among the voltage imbalance factors by employing different aggregation time intervals and a new aggregation interval of 2 min was proposed [11]. *Chen et al.* explored the various definitions of voltage imbalance and the suitable conditions to apply the definitions were found [12]. *Jayatunga et. al.* presented the deterministic methodologies in order to assess constituent components of the post-connection voltage imbalance level in an interconnected network and the line asymmetries was characterized by means of the positive-negative sequence coupling admittance of a line. [13]. *Wen et. al.* focused on the fast and accurate calculation of voltage imbalance factor of a three-phase power system and the proposed approximate algorithm required less clock cycles for digital signal processors [14].

In this study, the compatibility of the voltage dips and voltage imbalances occurred in an organized industrial zone are analyzed with respect to the limit values identified in the current standards. The voltage dips and voltage imbalances observed at 10-min intervals are revealed for a 6-month period and the outlier values are evaluated in detail.

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II. SUPPLY VOLTAGE CHARACTERISTICS OF THE ORGANIZED INDUSTRIAL ZONE

In this study, the phase-to-phase effective voltage values recorded at 10-min intervals for a 6-month period have been examined for a medium-voltage transformer located in the Organized Industrial Zone. The data recording covers the period from July 1, 2015 to December 31, 2015. In the stage of data analysis, the limits identified in the section of "Technical Quality" of "Regulation on Service Quality in Electricity Distribution and Retail Sale" are taken as the boundary values [15, 16]. The limits determined for supply voltage variations in the mentioned regulation are as follows: "Any of the measured 10-minutes-averages of voltage effective values should not be out of the interval of ±15%." The limits determined for voltage imbalances are also as follows: "The ratio of 10-minutes-averages of effective values of negative voltage components during measurement period over positive components should be 2% at the maximum for at least 95% of them."

In this respect, initially, the phase-to-phase effective voltage values recorded at 10-min intervals for a 6-month period are converted into the p.u. (per-unit) values. The supply voltage variations rising up to 1.15 p.u. and falling up to 0.85 p.u. are mainly evaluated. Afterwards, it is focused for each one-week period during 6 months that whether the voltage unbalance ratio exceeds the limit of 2% or not. In other words, the voltage unbalance ratios of about 958 data (~1008×0.95) in each week should not be over 2%. The formulations used for computing the voltage unbalance ratio (VUR) are given in Equations 1 and 2 [12, 17].

$$\%\mathrm{VUR} = \sqrt{\frac{1-\sqrt{3-6\beta}}{1+\sqrt{3-6\beta}}} \times 100 \qquad (1)$$

$$\beta = \frac{V_{ab}{}^4+V_{bc}{}^4+V_{ca}{}^4}{(V_{ab}{}^2+V_{bc}{}^2+V_{ca}{}^2)^2} \qquad (2)$$

L3-L2, L2-L1 and L1-L3 phase-to-phase effective voltage values belong to July 2015 are shown in Figure 1. The number of 15% and higher voltage dips are observed as 21 in the line voltage L3-L2, 25 in the line voltage L2-L1 and 17 in the line voltage L1-L3. Voltage swells do not exceed the limit of 15% during the entire month of July. The highest voltage dips in July are realized as 0.335 p.u and 66.5% for the line voltage L3-L2, 0.389 p.u. and 61.1% for the line voltage L2-L1 and, 0.353 p.u. and 64.7% for the line voltage L1-L3. The voltage unbalance ratios belong to July 2015 are also given in Figure 2. The voltage unbalance ratios of only 25 measurements are observed under 2% in this month. So, the limits identified for the voltage unbalance ratio are exceeded in each week of July.

Figure 3 illustrates the L3-L2, L2-L1 and L1-L3 phase-to-phase effective voltage values belong to August 2015. The number of 15% and bigger voltage dips are monitored as 16 in the line voltage L3-L2, 18 in the line voltage L2-L1 and 12 in the line voltage L1-L3. Voltage swells do not passed over the limit of 15% during the entire month of August. The biggest voltage dips in August are carried out as 0.228 p.u. and 77.2% for the line voltage L3-L2, 0.257 p.u. and 74.3% for the line voltage L2-L1 and, 0.278 p.u. and 72.2% for the line voltage L1-L3. In addition, the electricity interruption has been occurred between 08:40 and 18:10 on August 30, 2015. Figure 4 also presents the voltage unbalance ratios belong to August 2015. The voltage unbalance ratios of only 926 measurements are monitored fewer than 2% in this month. So, the limits specified for the voltage unbalance ratio are passed over in each week of July.

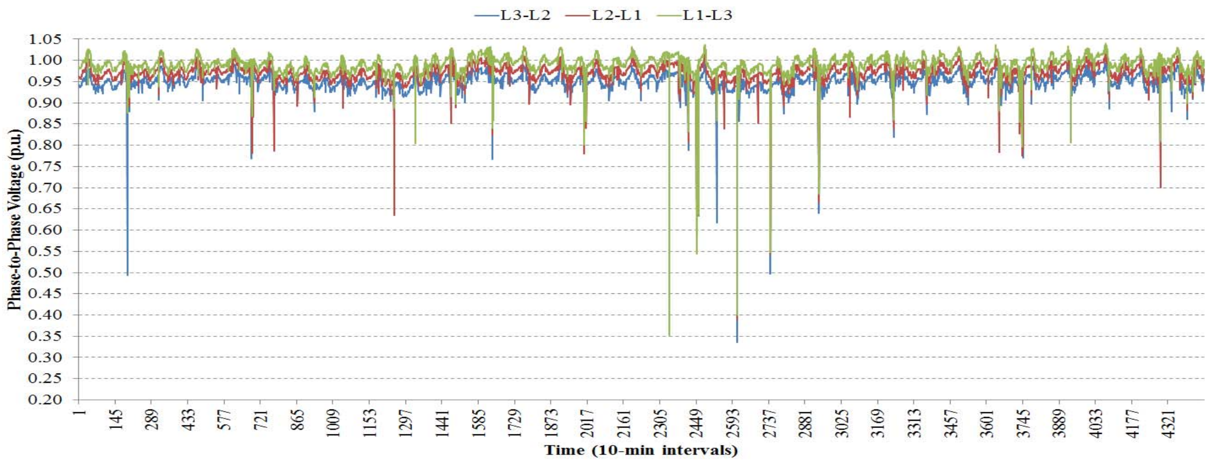

Fig. 1. The phase-to-phase effective voltage values belong to the July 2015

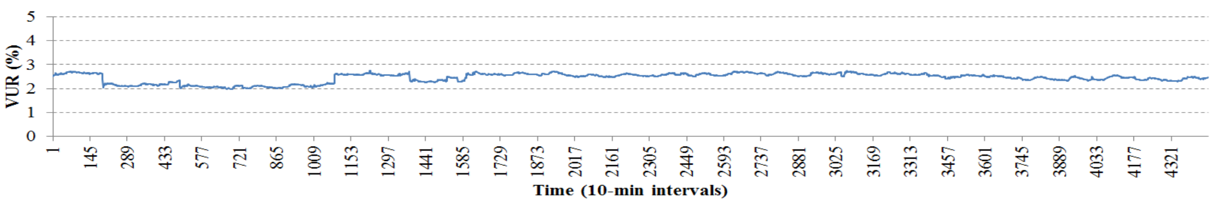

Fig. 2. The voltage unbalance ratios belong to the July 2015

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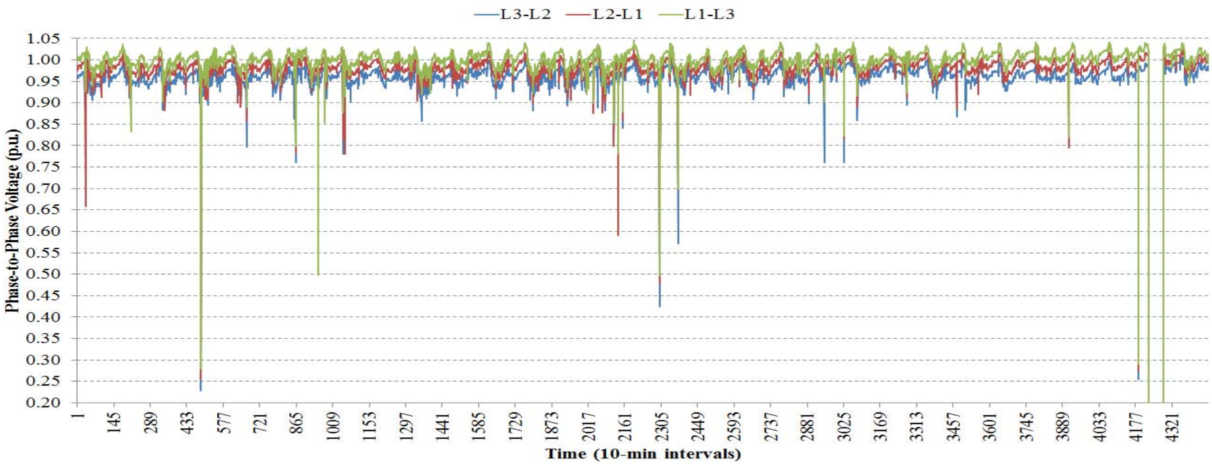

Fig. 3. The phase-to-phase effective voltage values belong to the August 2015

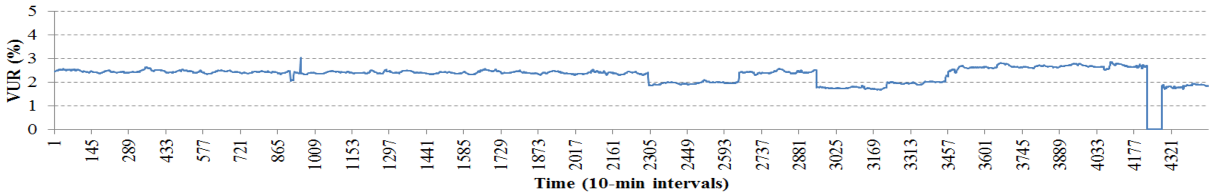

Fig. 4. The voltage unbalance ratios belong to the August 2015

L3-L2, L2-L1 and L1-L3 phase-to-phase effective voltage values belong to September 2015 are depicted in Figure 5. The number of 15% and higher voltage dips are counted as 14 in the line voltage L3-L2, 7 in the line voltage L2-L1 and 8 in the line voltage L1-L3. Voltage swells do not go beyond the limit of 15% during the entire month of September. The greatest voltage dips in September are occurred as 0.713 p.u. and 28.7% for the line voltage L3-L2, 0.759 p.u. and 24.1% for the line voltage L2-L1 and, 0.635 p.u. and %36.5 for the line voltage L1-L3. The voltage unbalance ratios belong to September 2015 are also provided in Figure 6. The voltage unbalance ratios of only 324 measurements are counted fewer than 2% in this month. So, the limits determined for the voltage unbalance ratio are gone beyond in each week of September.

Figure 7 shows the L3-L2, L2-L1 and L1-L3 phase-to-phase effective voltage values belong to October 2015. The number of 15% and higher voltage dips are observed as 18 in the line voltage L3-L2, 11 in the line voltage L2-L1 and 14 in the line voltage L1-L3. Voltage swells do not exceed the limit

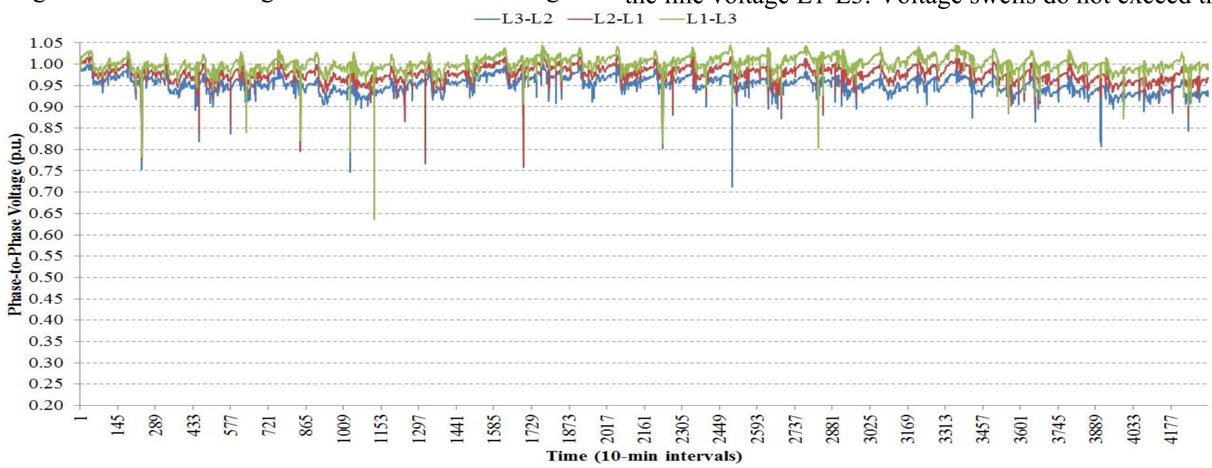

Fig. 5. The phase-to-phase effective voltage values belong to the September 2015

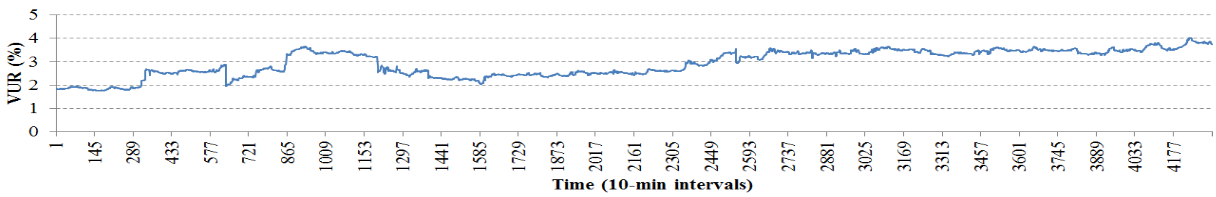

Fig. 6. The voltage unbalance ratios belong to the September 2015

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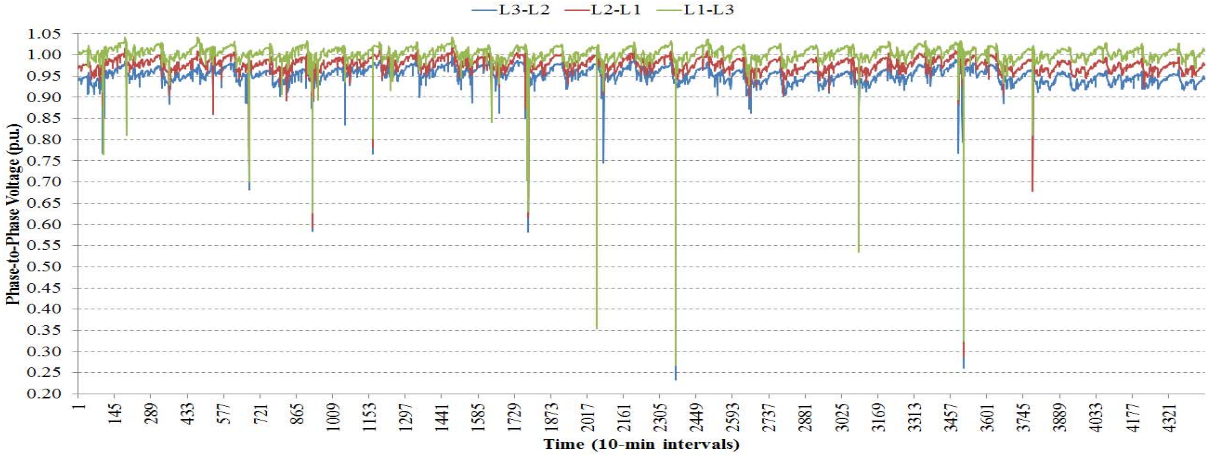

Fig. 7. The phase-to-phase effective voltage values belong to the October 2015

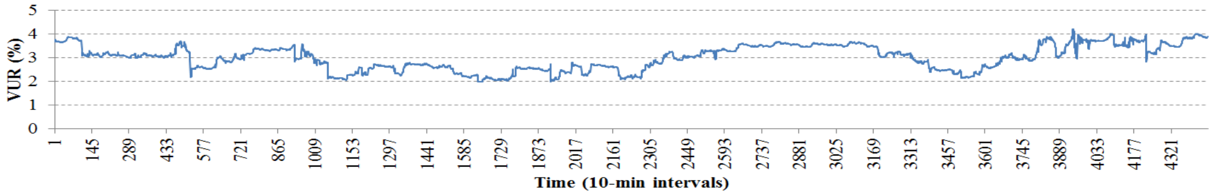

Fig. 8. The voltage unbalance ratios belong to the October 2015

of 15% during the entire month of October. The highest voltage dips in October are realized as 0.234 p.u. and 76.6% for the line voltage L3-L2 and, 0.267 p.u. and 73.3% for the line voltages L2-L1 and L1-L3. Figure 8 also demonstrates the voltage unbalance ratios belong to October 2015. The voltage unbalance ratios of only 18 measurements are observed under 2% in this month. So, the limits identified for the voltage unbalance ratio are exceeded in each week of October.

L3-L2, L2-L1 and L1-L3 phase-to-phase effective voltage values belong to November 2015 are illustrated in Figure 9. The number of 15% and bigger voltage dips are monitored as 12 in the line voltage L3-L2, 9 in the line voltage L2-L1 and 5 in the line voltage L1-L3. Voltage swells do not passed over the limit of 15% during the entire month of November. The biggest voltage dips in November are carried out as 0.291 p.u. and 70.9% for the line voltage L3-L2, 0.538 p.u. and 46.2% for the line voltage L2-L1 and, 0.352 p.u. and 64.8% for the line voltage L1-L3. The voltage unbalance ratios belong to November 2015 are also presented in Figure 10. There are not

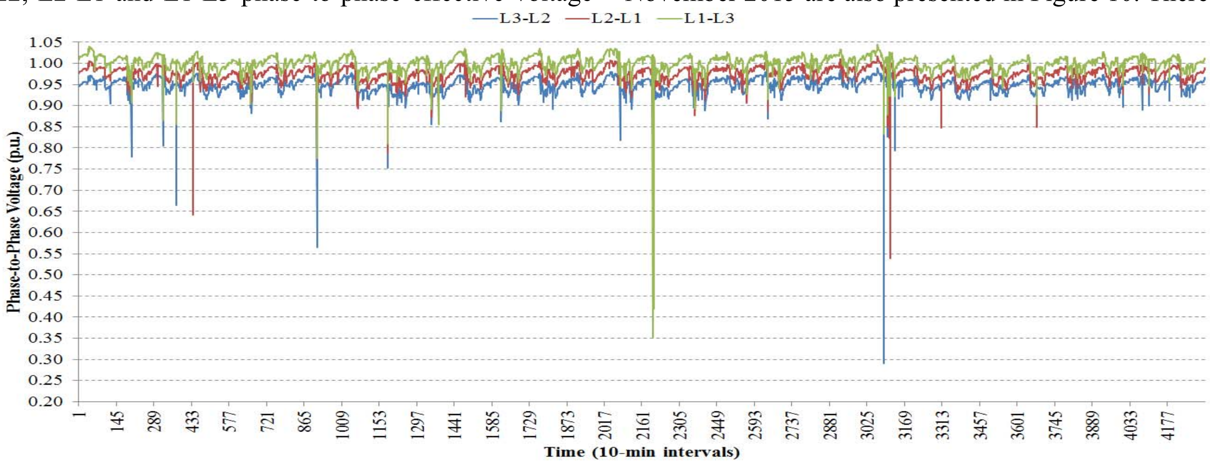

Fig. 9. The phase-to-phase effective voltage values belong to the November 2015

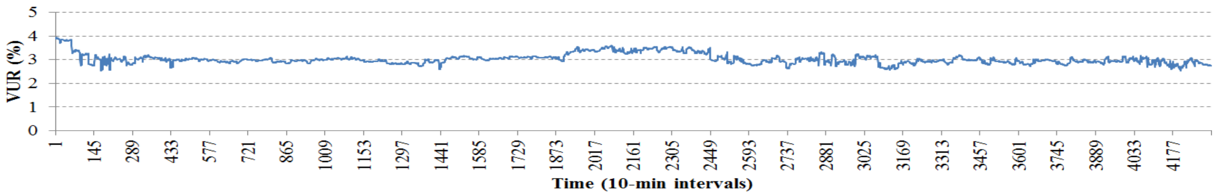

Fig. 10. The voltage unbalance ratios belong to the November 2015

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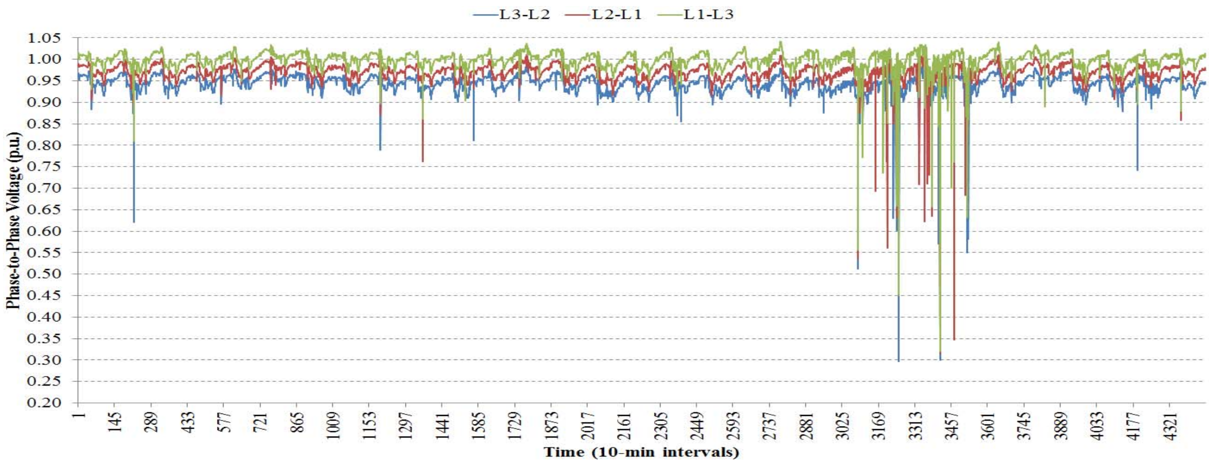

Fig. 11. The phase-to-phase effective voltage values belong to the December 2015

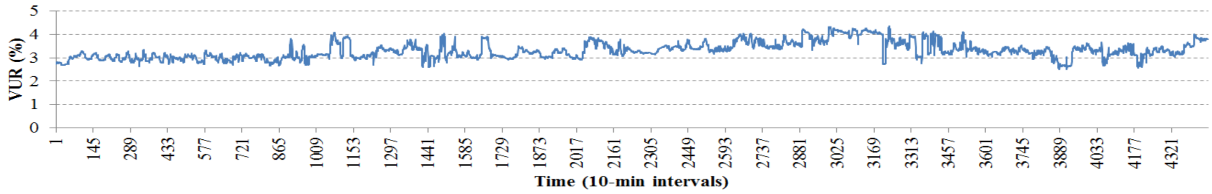

Fig. 12. The voltage unbalance ratios belong to the December 2015

any voltage unbalance ratios monitored fewer than 2% in this month. So, the limits specified for the voltage unbalance ratio are passed over in all weeks of November.

Figure 11 depicts the L3-L2, L2-L1 and L1-L3 phase-to-phase effective voltage values belong to December 2015. The number of 15% and higher voltage dips are counted as 24 in the line voltage L3-L2, 19 in the line voltage L2-L1 and 14 in the line voltage L1-L3. Voltage swells do not go beyond the limit of 15% during the entire month of December. The greatest voltage dips in December are occurred as 0.296 p.u. and 70.4% for the line voltage L3-L2, 0.316 p.u. and 68.4% for the line voltage L2-L1 and, 0.320 and 68% for the line voltage L1-L3. Figure 12 also provides the voltage unbalance ratios belong to December 2015. There are no voltage unbalance ratios counted fewer than 2% in this month. So, the limits determined for the voltage unbalance ratio are gone beyond in all weeks of December.

In case of comparing all of analyses, the number of 15% and higher voltage dips are found as 264 in total during the 6-month period. 105, 89 and 70 of them are observed in the line voltages L3-L2, L2-L1 and L1-L3, respectively. The maximum number of voltage dips is realized in July, while the minimum number of voltage dips is carried out in November. The biggest voltage dip is occurred with 0.228 p.u corresponding to the 77.2% in the line voltage L3-L2 in August. The number of voltage dips in each line during the 6-month period is shown in Figure 13. On the other hand, the number of voltage unbalance ratios above 2% is obtained as 25203 in total during the 6-month period. It is obvious that the excessive amounts of voltage imbalances are carried out in each week of the considered months. The maximum monthly average voltage unbalance ratio is measured as 3.31% in December, while the minimum monthly average voltage unbalance ratio is recorded as 2.31% in August. Figure 14 also illustrates the number of voltage unbalance during the 6-month period.

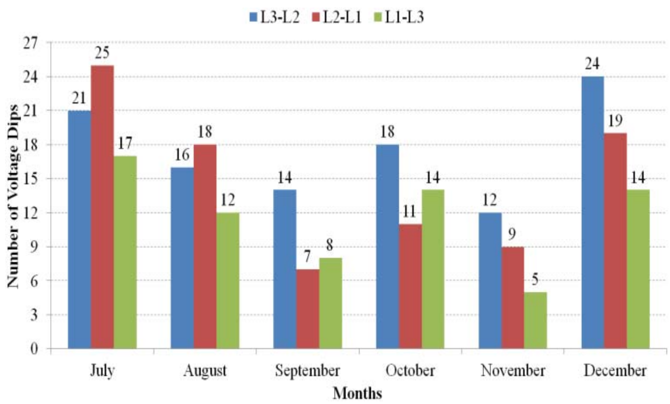

Fig. 13. The number of voltage dips for 6 months

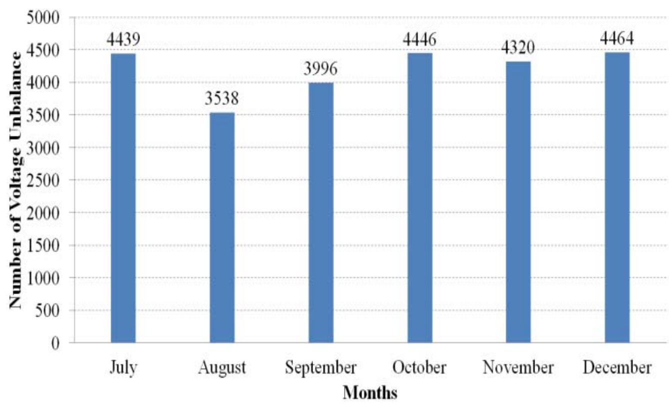

Fig. 14. The number of voltage unbalance for 6 months

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III. Conclusions

As a result of the standards-based boundary value analyses conducted for a medium-voltage transformer located in the Organized Industrial Zone, the maximum number of voltage dips is observed as 63 in July among all months and as 105 in L3-L2 among all lines. On the other hand, the maximum monthly average voltage unbalance ratio is measured as 3.31% in December. Overall, it is foreseen for the considered zone that the voltage dips are occurred in all of the phase-to-phase effective voltages at the same time due to the starting of large powerful three-phase motors. As well, the voltage imbalances are resulted from the unbalanced distribution of single-phase loads to all phases. For the purpose of taking the outlier values under the limits identified in the current standards, the large powerful three-phase motors should be started up gradually in order to reduce voltage dips and the single-phase loads should be distributed evenly in order to mitigate voltage imbalances in the considered zone.

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