Power quality analysis

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ArctiqDC – Arctic Datacenters project aims to strengthen the regional data centre industry's products, services, solutions and offerings to customers (parties) outside the region, nationally or internationally. This should be done by demonstrating and proving that; Investing and operating data centres in Arctic regions have low and among the lowest investment and operating costs in the world in terms of cooling and power distribution

Abstract

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The aim of this research was to find out the quality of the electric current in the data centers which are running on UPS compared to the data centers running without UPS and to recognize the opportunities to establish the data centers into areas where the power supply is reliable when there is no need to use expensive UPS devices. The outcome of this work is that no clear conclusions cannot be made because there are no significance differences between datasets and there are some data restrictions. However, three standard criteria of power quality, that could be computed from the data, are accepted with both systems, indicating that reliability of power supply is in good level in general. On the other hand, clearly the deviations of the variables are overall smaller in dataset with UPS than dataset without UPS so the use of UPS probably increases the stability of the signals.

Key words: data center; power distribution; UPS; power quality

Biomimetics and Intelligent Systems; University of Oulu

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CONTENT

1 Introduction

Data centers are growing power consumers and also rapidly growing industry. There is a strong need to increase the use of renewable energy and to get off fossil fuels in data center energy consumption. The increased use of renewables brings about more intermittency on the grid, because it is not always available, and therefore the grid needs to be more stable. One solution is to use an Uninterruptible Power Supply (UPS) device, which ensures the continuous and high-power quality as well as handles the grid power failures [1]. With the help of the UPS system the sinusoidal output voltage can be regulated, with low total harmonics distortion (THD), and high input power factor in spite of the changes in the grid voltage [2, 3]. The UPS devices are based on batteries and/or diesel generators.

The goal of this research was to find out the power quality in the data centers running on UPS system compared to the centers running without UPS. There are several disadvantages of using UPS systems. For example, the system, especially batteries, can be expensive, the installation is a big investment, and the continuous maintenance is needed. The aim of this research was also to study and gather some metrics of the opportunities if data centers can be run without expensive UPS equipment, in Nordic areas where the power supply is reliable enough.

2 Data description

There were two datasets available called Data_UPS and Data_nonUPS. The dataset Data_UPS consists of samples measured from electric current when UPS device is used and it is collected from RISE's ICE data center in Luleå, Sweden. The dataset Data_nonUPS includes samples measured without UPS device and it is collected from BTDC data center in Boden, Sweden. Since the datasets were collected from different data centers, they were collected in separate occasions, but the periods were equal, one week. Both datasets include 20 161 samples measured with 30 seconds time gap and about 40 variables. There were about 1900 missing values only. The most significant variables were 3-phase voltage measurements and total harmonic distortion (THD). In Fig. 1, can be seen how voltage values varies during time and between datasets. The voltage values from the Data_UPS are on the left column and the values from the Data_nonUPS are on the right column. The corresponding plots for THD values are shown in Fig.2. As can be seen, there are visually seen differences between the data depending on if the Data_UPS or Data_nonUPS is utilized. Especially, the plots of THD are significant different between the datasets in Fig.2. THD values of Data_nonUPS dataset are discretized to first decimal, but this probably relates to setting how the data samples are recorded rather than the nature of the measurements. Total ranges (i.e., minimum to maximum) are quite similar in both datasets.

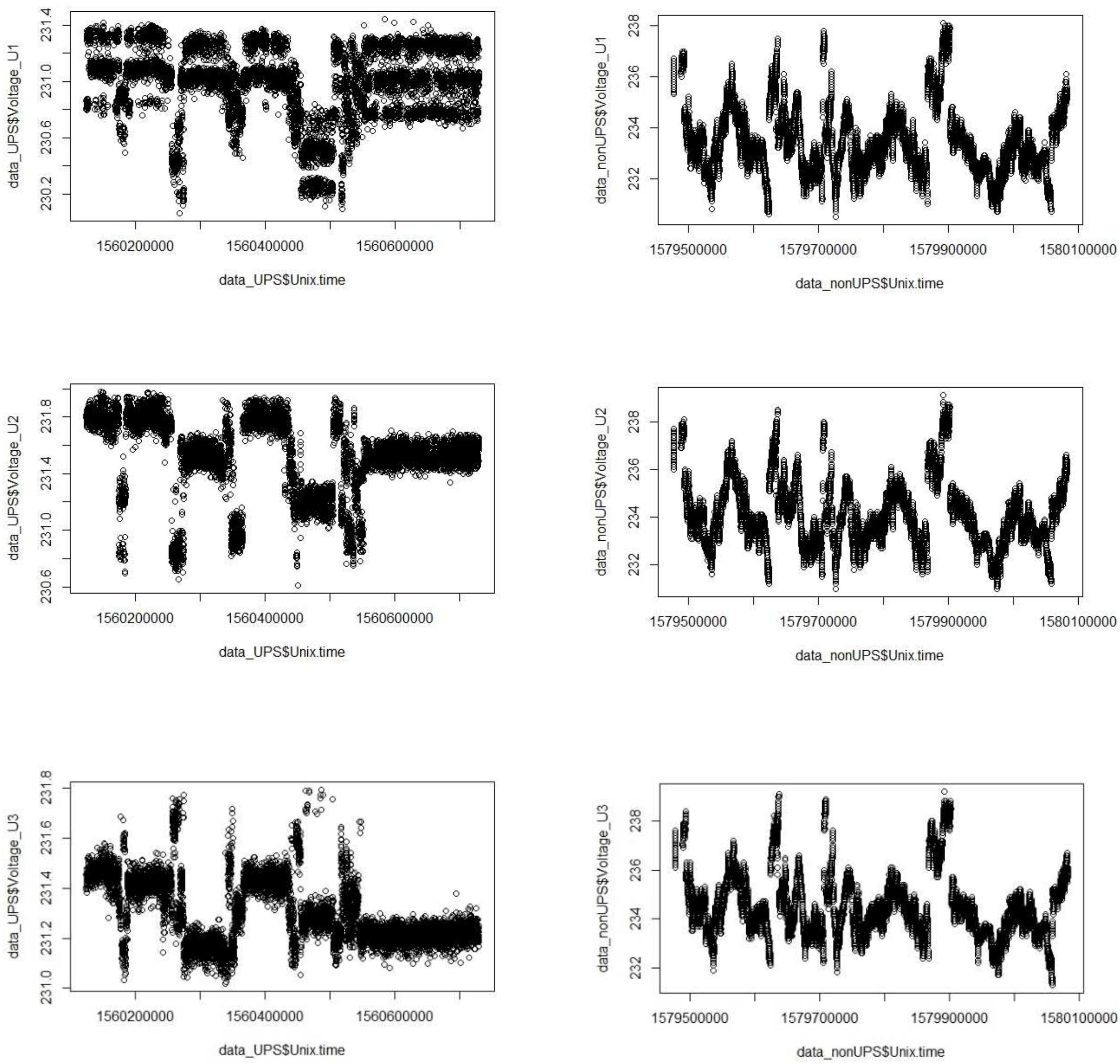

Figure 1. The voltage values of componets U1, U2 and U3 (y-axis) compared between Data_UPS (left column) and Data_nonUPS (right column) in relation to time (x-axis).

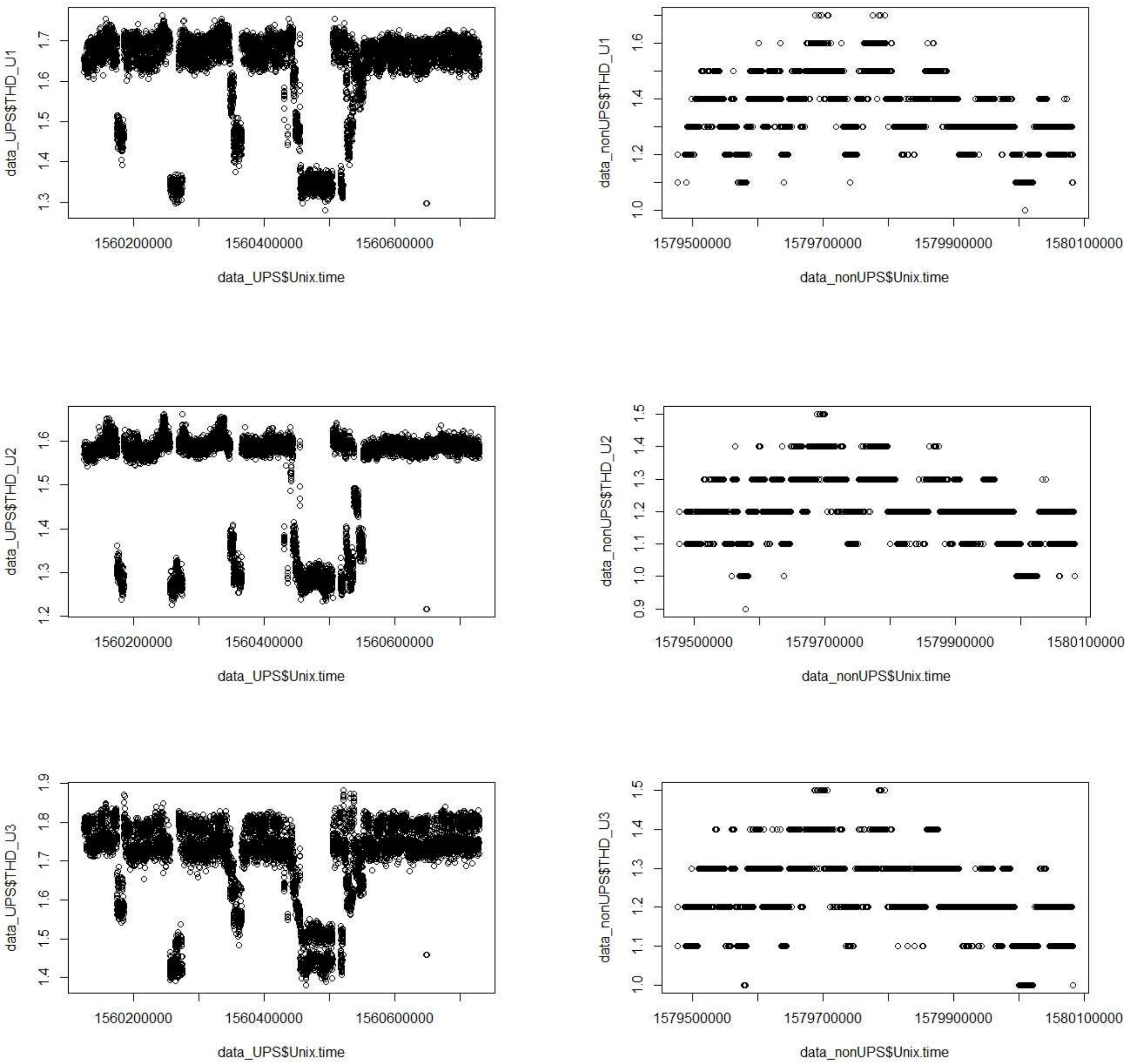

Figure 2. The THD values of components U1, U2 and U3 (y-axis) compared between Data_UPS (left column) and Data_nonUPS (right column) in relation to time (x-axis).

3 Criteria description

The quality of the datasets was explored using a specified criteria. It is typical to use 7 standard criteria, named under. However, only first three of them are studied in this work due to low sampling rate of data, and the analyses of high frequency content of the signals cannot be done.

- **Voltage asymmetry**
- **Variations in voltage**
- **Total harmonic distortion (THD)**
- Individual overtones *(too large time gap)*
- Momentary lowering of voltage (*too large time gap)*
- Momentary rise of voltage *(too large time gap)*
- Rapid voltage change *(too large time gap)*

Each criterion was calculated from the data based on the definition of the International Electrotechnical Commission (IEC) power quality measurement criterion. The voltage asymmetry describes the state in which the 3-phase voltages differ in amplitude or the phase angle differs from their normal 120° phase, or both [4, 5]. The asymmetry (4) is calculated in the 10-min sequentially window, which means that there are 20 samples in one window [6]. First, the root-mean-square (rms) voltages U_{rms_k} (1) are calculated for each 3-phase voltage vector U_k $(k = 1{,}2\ or\ 3)$ over the 10 min windows:

$$U_{rms_k} = \sqrt{\frac{1}{N}\left(\sum_{i=1}^{N} U_{k_i}^2\right)}, \tag{1}$$

where *N* is the number of the values (U_k) in the 10 min window, in this case $N = 20$, and k refers the voltage phases vectors $U_1, U_2\ and\ U_3$. And, after that the final vector U_{rms} (2) is calculated between the rms of 3-phase voltage vectors U_{rms_k}:

$$U_{rms} = \sqrt{\frac{1}{3}\left(\sum_{k=1}^{3} U_{rms_k}^2\right)}. \tag{2}$$

Then, the deviation of the voltage (3) is calculated between the 3-phase voltage vectors U_k and rms voltage vector U_{rms}:

$$U_{dev} = \max(U_1, U_2, U_3) - U_{rms}. \tag{3}$$

Finally, the asymmetry of voltage (4) is the relation between the voltage deviations and the rms voltages:

$$Asym(\%) = \frac{U_{dev}}{U_{rms}} * 100\%. \tag{4}$$

Furthermore, the maximum, minimum and *95%* of samples of asymmetry are calculated. The variations in voltage for each phase are defined as maximum, minimum and *95%* of the samples of U_{rms_k} (1), where $k = 1{:}3$. The third criterion is the rms of the THD (5), which is calculated in the 10-min sequentially window for each phase:

$$THD_{rms_k} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} THD_{k_i}^2}, \quad (5)$$

where N is the number of the values (THD_k) in the 10 min window. Thereafter, the maximum, minimum and *95%* of the samples of THD_{rms_k} are calculated.

4 Data analysis

The criteria test results of these two datasets are shown in table 1. In the first column, the criterion and the safety range for that in italics, are shown. The second column shows the used descriptive statistic and third column points at the maximum, minimum and *95%* of the calculated criteria values in the Data_UPS. Correspondingly, the fifth column shows the criteria results for Data_nonUPS. As can be seen from the fourth and the last columns, the range of the criteria in both datasets are within safety range.

The differences between datasets can be seen more closely in Fig.3, Fig.4 and Fig.5. In Fig. 3, the boxplots of the voltage asymmetry show clearly that the deviation of the asymmetry is larger with dataset Data_nonUPS. The mean of the asymmetry differs in datasets and at all the values are smaller with dataset Data_UPS. The boxplots of the rms of voltage are similar to asymmetry in Fig.4. At all, the values are smaller with Data_UPS than Data_nonUPS, whereas the boxplots of THD are totally opposite in Fig.5. The values of THD are larger with Data_UPS than Data_nonUPS. Also, the deviations are much smaller in the Data_UPS than Data_nonUPS.

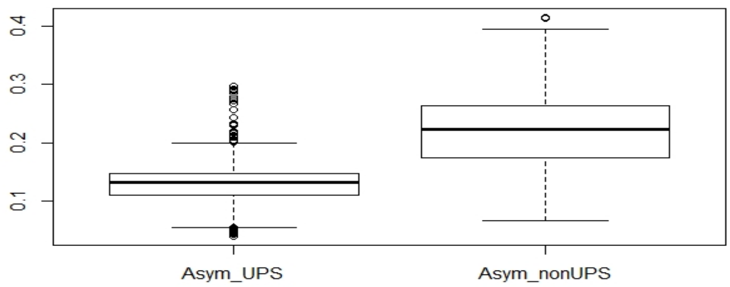

Figure 3. Boxplots of the voltage assymetry in both datasets. Data_UPS on the left and Data_nonUPS on the right.

Table 1. The main results of the criteria in both datasets Data_UPS and Data_nonUPS.

Criterion	Descriptive statistics	Data_UPS	Criterion result for UPS	Data_nonUPS	Criterion result for nonUPS
Voltage asymmetry ***Asym under 2% every ten minutes***	**Min**	0,04%	*accepted*	0,07%	*accepted*
	Max	0,30%	*accepted*	0,41%	*accepted*
	95%	0,18%	*accepted*	0,32%	*accepted*
Variations in voltage (U1, U2 & U3) ***207 V – 253 V*** ***The voltage rms for every ten minutes must be between 90% and 110% of the reference voltage.***	**Min**	*U1_rms*: 230,25 *U2_rms*: 230,80 *U3_rms*: 231,09	*accepted*	*U1_rms:* 230,86 *U2_rms:* 231,35 *U3_rms:* 231,59	*accepted*
	Max	*U1_rms:* 231,34 *U2_rms:* 231,90 *U3_rms:* 231,67	*accepted*	*U1_rms:* 237,77 *U2_rms:* 238,43 *U3_rms:* 238,57	*accepted*
	95%	*U1_rms:* 231,25 *U2_rms:* 231,84 *U3_rms:* 231,49	*accepted*	*U1_rms:* 236,28 *U2_rms:* 236,99 *U3_rms:* 237,41	*accepted*
Total harmonic distortion (THD) **(U1, U2 & U3)** ***THD ≤ 8%*** ***The values of THD for every ten minutes must be equal to or less than 8%***	**Min**	*THD_U1:* 1,32 *THD_U2:* 1,25 *THD_U3:* 1,41	*accepted*	*THD_U1:* 1,10 *THD_U2:* 0,10 *THD_U3:* 1,00	*accepted*
	Max	*THD_U1:* 1,73 *THD_U2:* 1,65 *THD_U3:* 1,84	*accepted*	*THD_U1:* 1,61 *THD_U2:* 1,43 *THD_U3:* 1,47	*accepted*
	95%	*THD_U1:* 1,71 *THD_U2:* 1,61 *THD_U3:* 1,79	*accepted*	*THD_U1:* 1,56 *THD_U2:* 1,37 *THD_U3:* 1,40	*accepted*

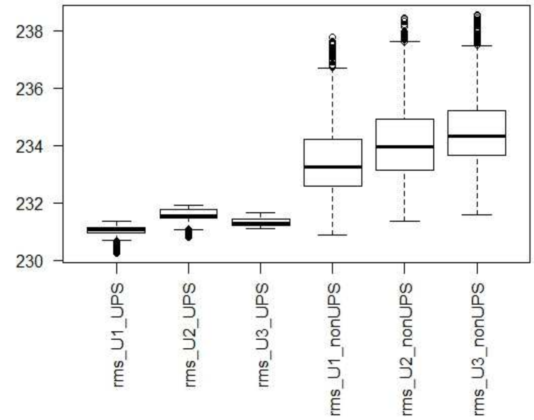

Figure 4. Boxplots of the rms of the voltage values in both datasets. First three on the lefth are from Data_UPS and the last three from the Data_nonUPS.

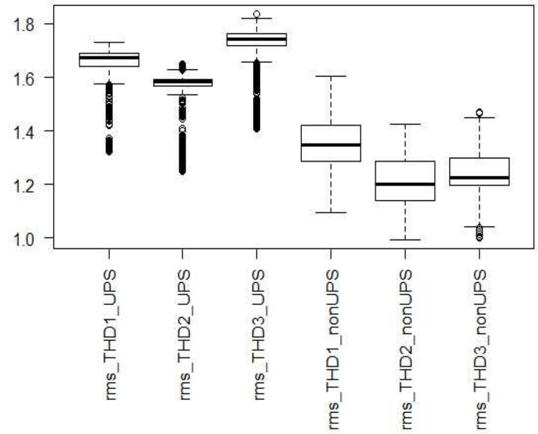

Figure 5. Boxplots of the THD values in both datasets. First three on the lefth are from Data_UPS and the last three from the Data_nonUPS.

5 Discussion and conclusion

The aim of this work was to find out is the use of UPS device resonable with data center having reliable power supply. The quality of the electric current in the data center was explored with two cases, when UPS is used and UPS is not used. Two different datasets from two different data centers were analyzed using a specified criteria. There were 7 criteria, but only three of them were possible to test due to the data restrictions. The sampling rate of the data was too low to perform analysis of high frequency content of the voltage signals. We found out that there is no significance difference between the quality of the datasets based on the criteria tests and power quality in both systems with and without UPS are accepted. There are still some differences seen in visual inspection. The comparison between the datasets may be hindered by the fact, that the datasets are collected during different periods of time from different data centers and there may be some dimensional accuracy differences, for example, the above-mentioned discretization/rounding problem. These problems can be clearly seen in Fig. 2, where the plots from different datasets differs exceptionally much. This analysis could be extended if these detected problems can be eliminated.

Main conclusions of this research:

- There are visually differences between datasets were UPS is utilized or not utilized. Especially, the THD values behave differently
- The deviation of the voltage asymmetry is larger when UPS is not utilized
- The rms voltage behaves similarly as asymmetry
- The values and their deviations are smaller when UPS is utilized
- THD values differ form other values, they are larger when UPS is utilized
- Visually, the use of UPS device increases the stability of the data
- Power quality criteria are accepted with both systems

One special observation in this work was the dissimilarity of the THD values plots between the datasets in Fig.5. It is not clear why THD values behaves differently compared to the voltage asymmetry and the voltage values. This arises a question, if there is some natural explanation for that or is there some kind of measurement fault in the data. The outcome of this work is that no clear conclusions cannot be made because of the differences between datasets are not significant in a light of data restrictions and inaccuracies mentioned above. Clearly, the deviations of the variables are overall smaller in the dataset Data_UPS than the Data_nonUPS. Hence, the stability of the Data_UPS is better than Data_nonUPS. On the other hand, three standard criteria of power quality, that could be computed from the data, are accepted with both systems, indicating that reliability of power supply is in good level in general.

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