VOLTAGE DIPS AND SWELLS IN DANISH DISTRIBUTION GRIDS

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ABSTRACT

This paper addresses the disturbances caused by voltage swells and in particular voltage dips that affect industrial customers' equipment. The main focus is what the distribution companies can do to these voltage disturbances.
To find out how big a problem it is, an analysis is conducted based on practical measurement and a comparison with the generic immunity classes for industrial equipment.

Furthermore all the voltage disturbances, which occurred in the distribution grid, are analysed in respect as to why they occurred.
This information can help the distribution companies and the industrial customers to understand the nature of voltage disturbance in the distribution grid.

INTRODUCTION

This paper examines the issue of voltage dips and voltage swells specifically, under the broader scope of power quality, by practical measurements carried out at a number of Danish Medium Voltage industrial customers.

Voltage Swells and, in particular, Voltage Dips occur on a regular basis in the Medium Voltage grid, the causes ranging from brief changes due to switching or coupling of components to temporary faults that clear automatically in short order.

These brief, but sometimes large, changes in the voltage can have an adverse effect for some customers who may have sensitive equipment that may be affected by these rapid changes in the voltage [1].

The particular focus on Voltage Dips in this paper is due to the stronger effect this phenomenon has on industrial customers as compared to actual interruptions, given the average SAIDI of less than 21 minutes and the SAIFI barely getting above 0.4 in recent years in Denmark [2].

Dialogue between sensitive industries and distribution companies has arrived at the same conclusion, that it is often the brief, unexpected interruptions that is the main concern – rather than extended periods of supply interruptions.

Thus a measurement campaign, with 11 industries geographically spread out across Denmark, was initiated – with the purpose of examining the actual voltage changes occurring, and to determine if there was any prevalent type that were especially troublesome for sensitive industrial customers and could be mitigated by the distribution companies.

VOLTAGE VARIATION

Rapid changes in the supply voltage mainly fall into three categories:

- Rapid Voltage Changes, which are rapid RMS voltage changes, within +/- 10 % of the normal supply voltage.
- Voltage Swells, which are Rapid Voltage Changes, where the RMS voltage changes to above 110 % of the supply voltage.
- Voltage Dips, which are Rapid Voltage Changes, where the RMS voltage changes to below 90 % of the supply voltage.

Actual supply interruptions are not considered, nor did they occur during the measurements.

Supply voltage allowance

The quality of supply in Denmark is generally set by the European EN 50160 standard [3], which defines the acceptable variations under normal operations to be any variation within +/- 10 % of the declared voltage for medium voltage. Asides from this requirement, no requirements for Rapid Voltage Changes, Swells or Dips are given.

Many Danish distribution companies still aim to have the Rapid Voltage Changes, Swells and Dips within older guidelines – meaning that they generally aim to keep Rapid Voltage Changes below 4 %, and completely avoid any Voltage Swells as well as Dips – although this is not an actual requirement.

Immunities

Industrial equipment should in general be immune to some disturbances. In this case, IEC 61000-6-2 has been used to set an acceptable level of disturbance, as this is applicable for industrial environments and is harmonized as a European Norm – meaning manufacturers will have to argue the immunity of their individual pieces of equipment, if they do not meet the requirements in the standard.

IEC 61000-6-2 cover from equipment continuing normal operations automatically after a single cycle of 0 % residual voltage, up to functioning within the +/- % band.

Figure 1 shows the various immunities, although the requirements of a single cycle of 0 % residual voltage are not shown, nor are Voltage Swells or actual interruptions included.

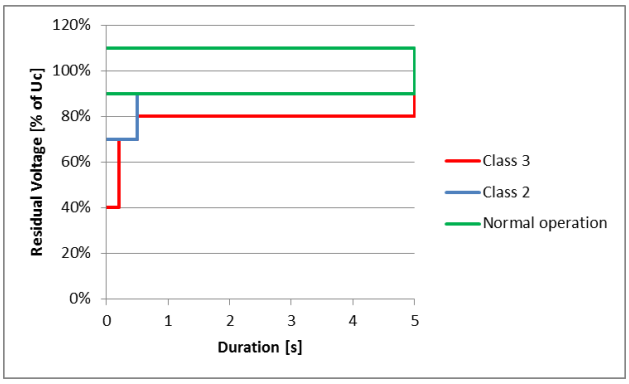

Figure 1: Industrial voltage immunity (IEC 61000-6-2).

Instrument setup

The instruments used are regular Class-A power quality meters, connected to the existing medium voltage measurement transformers.

They are connected with a Y-connection, using the Peterson coil as a neutral point – this connection was used in order to include as many voltage variations as possible – even single-line faults that should not have practical impacts to most machinery.

The sensitivity of detecting voltage changes was tuned at each point to detect anything larger than a single change in the tap-changers of the supplying transformers.

MEASUREMENT RESULTS

In total 11 sites were measured during the campaign, in two different rounds (each synchronous area of Denmark were measured separately) and each were measured for at least 6 months – but most sites are measured for a full year, as the IEC 61000-4-30 recommends in annex B, and a few as much as 18 months due to organizational issues.

Figure 2 shows the distribution of where causes of the voltage changes originate, after the initial look-up in the distribution and transmission logs, of the total 542 registered Rapid Voltage Changes.

The unknown origin will be eliminated during the process as either the exact cause, thus identifying the location, or as the events fall within the groups of events that are eliminated from detailed analysis.

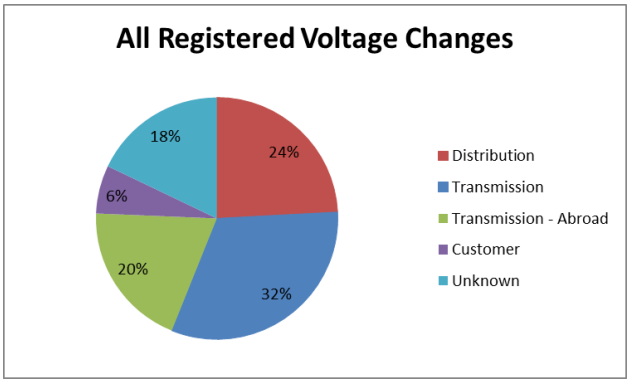

Figure 2: Distribution of all registered Voltage Changes.

Assuming that any variation within the normal operating band of +/- 10 % of the declared voltage will not cause interruptions within the equipment, nor that Voltage Swells occurs (there are some, but all are caused by the customers themselves), the focus is turned to Voltage Dips mainly – the distribution of which is shown in Figure 3.

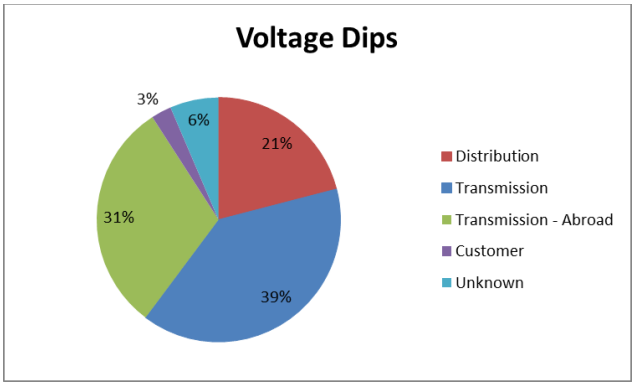

Figure 3: Distribution of Voltage Dips.

As can be seen on Figure 3, the transmission level, nationally and abroad, is a dominating source of Voltage Dips. This is in part expected, as an event on the transmission level will be more likely to propagate down the system than a distribution event will be to propagate upwards.

It does still show that 70 % of the recorded events (some severe enough to be present in the system as a whole) are outside the sphere of influence of the distribution companies, leaving only approximately 20 % of the recorded events being possible to influence in theory.

MEASUREMENT ANALYSIS

The measurements are generally analysed individually after categorizing them. The starting point for the main part of the exclusion of categories and types of events are the 445 events presented in Figure 4.

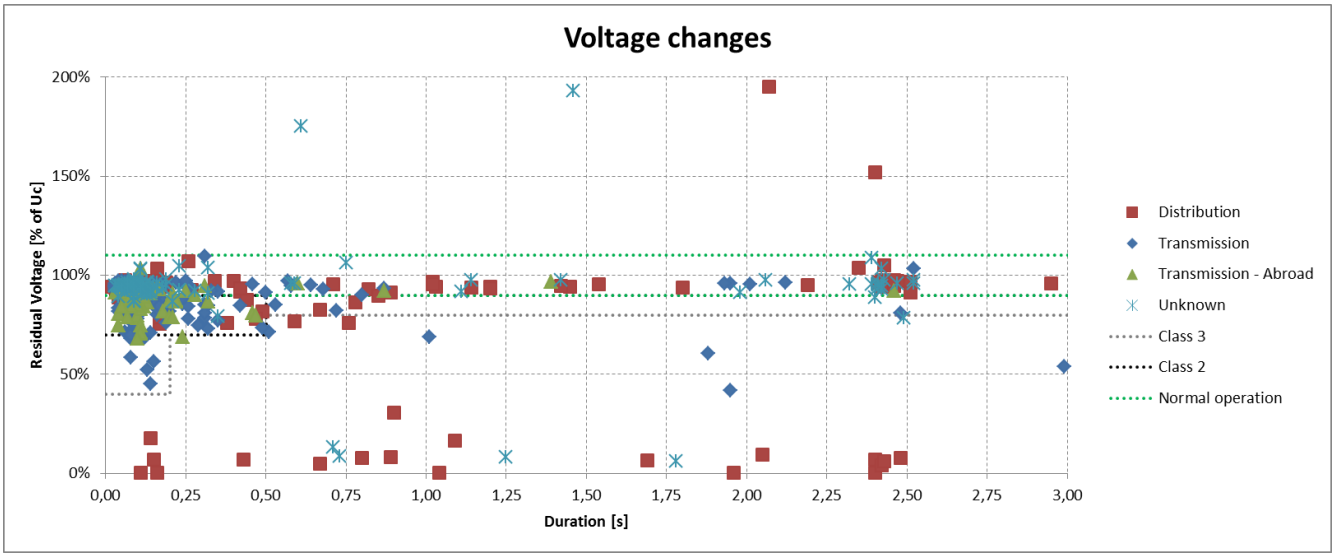

Figure 4: All registered voltage changes, except those caused by the customers themselves.

The four events between 150 and 200 % are caused by the selected method of measurement, and are all eliminated later as they are caused by single-phase to ground faults, where the measurement instrument triggers on one of the other two phases – effectively showing the combined voltage of the phases and the Peterson coil.

As can be seen, from the figure, the majority of the events are within the normal operating area of the grid, or with duration of less than 0.25 seconds.

Elimination of categories and types of events

From a distribution point-of-view it is limited how many of the recorded events that are relevant to examine in more detail, based on the objective of locating potential disturbances to the voltage that are an issue to sensitive industrial customers and can be prevented by the distribution companies.

To this end the events are filtered out on the following criteria:

Removal of normal operation category
All Rapid Voltage Changes within the normal +/- 10 % of the declared voltage are removed, as equipment should continue to function as normal within this operating band.

As the voltage is expected to fluctuate continuously within this band during normal operation of the grid, this should not cause disturbances to any loads.

Removal of transmission categories
Voltage events that occur on the transmission level are removed, as they are nigh impossible for the distribution companies to prevent.
Transmission events in neighbouring countries are also removed, as the distribution companies have, if possible, even less influence to prevent these.

Removal of class 2 and 3 immunity categories
While the performance criterion for the immunity classes 2 and 3 both allow for temporary loss of function, they should be either self-recoverable or recoverable by, effectively, a push of a button.

This is assumed to be procedures that should not result in extended down-time – and thus events within these two categories are also removed.

Only 13 of the 89 events in class 2 and 3 are from distribution sources, the rest are from causes stemming from the transmission system.

Removal of single-phase to ground faults
Single-phase to ground faults are removed as these will have little to no practical effect on most loads – only 3-phase loads connected directly to the medium voltage grid should be affected by these.

The medium voltage grid is grounded through Peterson coils, and the transformers transforming to lower voltage are delta-wye – the effect of a single-phase fault in the medium voltage grid should thus be limited for the most part.

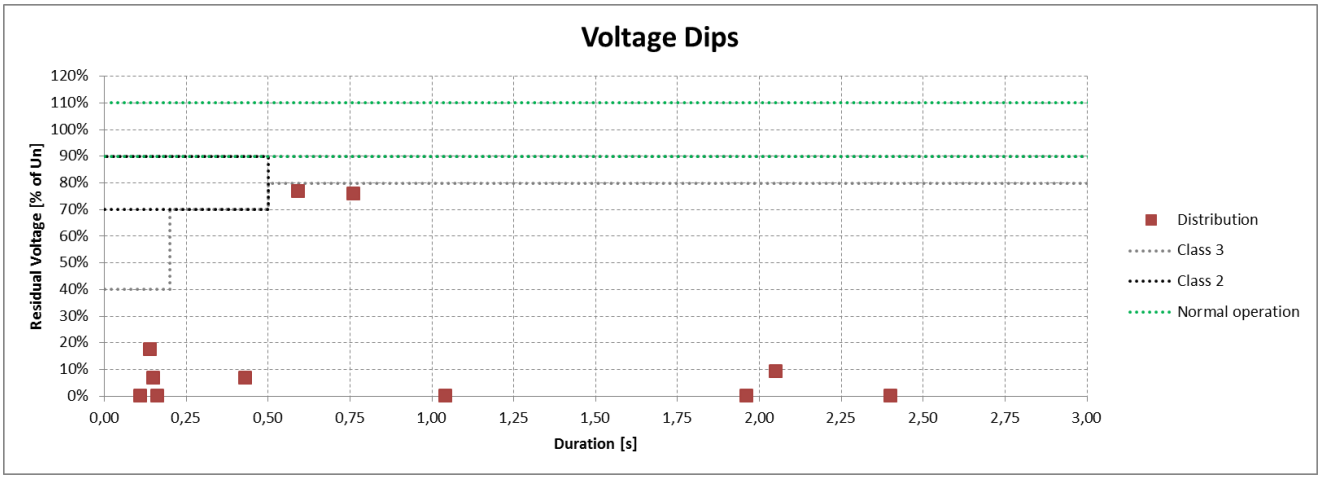

Figure 5: Remaining Voltage Dips for analysis after eliminating all groups and types of events.

Identification of remaining events

With the removal of all events either stemming from sources that cannot be mitigated by distribution companies, or that should not cause issues for properly immune industrial equipment a total of 13 events remains, as shown in Figure 5. The figure only shows 11 distinct points, but two of them (0.11 and 2.4 seconds) each has two separate events at almost the exact same spot.

The events can be tallied into the following causes:

Damage caused by digging

One event was caused by a company digging in the ground and digging partly through a cable, causing a single-phase to ground short circuit.
This type of event should be avoidable, but requires that third parties adhere to their instructions and never dig without checking for power cables.

Ground connection not in place in 3rd party facility

One event is caused by proper grounding having been forgotten in a 3rd party facility connected to the medium voltage grid.
It is classed as originating in the distribution grid, as it is not caused by the industrial customer at the measurement point, but is caused by another customer.
This should be an avoidable event.

Switching of measurement circuit

Two events are switching of the measurement circuits locally and are thus not actual voltage events.

Switching during faults and fault clearing

Three events are from attempted re-connections to localize a fault in order to isolate and repair it.
While technically avoidable, not doing so would extend the outage time for many customers, who can be reconnected quickly due to quickly being able to isolate the faulty part of the grid.

Planned switching

Six events are caused by planned manual switching close to the measurement point (and thus the customer) or planned revision of stations.
Minimization of the number of these events may also be possible by optimizing the protection schemes used to disconnect as close as possible to an occurring fault in the grid.

These can be minimized in their effect on customers through dialogue directly with the customer to determine when the most sensitive equipment is not operating. This may lead to running reserve configurations for longer than absolutely required, but that may be an overall better solution than causing problems for large sensitive industrial customers.

DISCUSSION

One of the main intentions was to identify the voltage events causing disruptions to sensitive industrial customers, however while the customers were all volunteering companies, the year over which the measurements were taking place appeared to be too long. As the project came to the point of data analysis, the industrial customers had generally completely forgotten, and had not kept notes or logs of disruptions in the production system.

Only two actual reports were made by one of the participating industrial companies.
An event with 70 % residual voltage in approximately 1 second caused a production interruption, but a later event to 40 % residual voltage for approximately 2 seconds did not.
This seems to indicate that the actual ability of the sensitive machinery to continue during a voltage event is not fixed, possibly varying with the actual work being done at the time.

CONCLUSION

Of all the Rapid Voltage Changes recorded, only 2.4 % of them were caused by events within the distribution grid and fell outside the range of what customer's equipment is reasonably expected to be immune to.

Of those 13 events left for analysis,

- two should not have happened, but involve a 3rd party,
- two were not actual events, but switching of the measurement circuits,
- three could possibly be minimized by optimizing protection schemes and
- six were planned switching, which could most likely be planned in a manner to minimize their impact on sensitive customers.

The clear majority of the voltage changes were caused by events on the transmission level, and cannot be mitigated by distribution companies. They are, however still mostly within the immunity levels that can be expected of industrial equipment.

Involvement of private industries in year-long measurement campaigns requires more effort and commitment than a verbal agreement to make detailed analysis possible. What they need to log, and how, has to be considered and agreed in writing as disruptions due to voltage event are too few and far apart to keep their attention, and the details of production at the time appears to have a significant impact on the ability to withstand voltage events.

REFERENCES

[1] P. Heine et. al., 2001, "Estimating the annual frequency and cost of voltage sags for customers of the five Finnish distribution companies", *CIRED conference 2001*.

[2] Council of European Energy Regulators, 2015, *CEER Benchmarking Report 5.2 on the Continuity of Electricity Supply*, CEER.

[3] CENELEC, 2010, *Voltage characteristics of electricity supplied by public electricity networks*.