CUSTOMER COSTS DUE TO MAJOR VOLTAGE DISTURBANCES: ESTIMATIONS FOR AN URBAN DISTRIBUTION NETWORK IN SWITZERLAND

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ABSTRACT

Power quality (PQ) is moving into focus, as the integration of renewable distributed generation affects an increasing number of sensitive electronic apparatus. Statistics about major voltage dips or swells are rare. Reliability measures of outages (SAIDI, SAIFI) have been in the foreground so far. ewz, a Swiss urban network operator, is building a representative network of PQ measurement points, which will enable ewz to monitor PQ-indices like SARFI-X, $SARFI_{curve}$ and $SARFI_{system}$ and to estimate customer costs caused by voltage disturbances. First results of the network's SARFI counts and of a PQ cost model are presented. A comparison of the costs per capita with other countries shows corresponding values.

INTRODUCTION

The "Elektrizitätswerk der Stadt Zürich" (ewz) is an urban distribution network operator in Switzerland (15 HV/MV-substations, 83 km 150 kV-cables, resp. 72 km overhead lines, 800 MV/LV-stations, 830 km MV-cables, 280'000 LV-connections, 3000 GWh energy delivery). ewz has monitored reliability parameters like SAIDI and SAIFI for several years already and has set up a cost-model to estimate customer costs due to unplanned outages [1] [2]. As the distribution grid undergoes a rapid change through the integration of distributed generation and increasingly sensitive electronic equipment, a monitoring system for PQ events is needed for PQ management by the system operator. [3] asserts that "costs due to voltage disturbances on a national level are still unknown or uncertain in many European countries." In order to collect the required data for ewz, a representative PQ network of measuring stations is being built. PQ will be analysed by detecting and counting major voltage events, by evolving some quality indices and furthermore by estimating the possible customer costs caused by major voltage events in an urban distribution network in Switzerland.
The aim of the paper is to present the existing and developing PQ measurement network, to show first results of three years of measurement, to introduce the process for estimating customer costs and to display the results gained. To determine major events with impact on customer cost industry immunity curves CBEMA (Computer Business Equipment Manufacturer Association), ITIC (Information Technology Industry Council) and SEMI (Semiconductor Equipment and Material International Group) are applied. The process of customer cost estimation is introduced and results of the calculation are displayed including a comparison with statistic data of other countries.

MEASUREMENTS OF PQ-EVENTS

Figure 1 schematically depicts the network and the corresponding monitoring points. As we see from the year of availability on the right side of the figure, the network is installed for the two upper voltage levels but not yet finished for the two lower levels. Therefore, the focus is on the 11/22 kV-level with 45 monitoring points at MV-busbars of 15 HV/MV substations. On the left side of the figure the number of planned and actual measurement points is given.

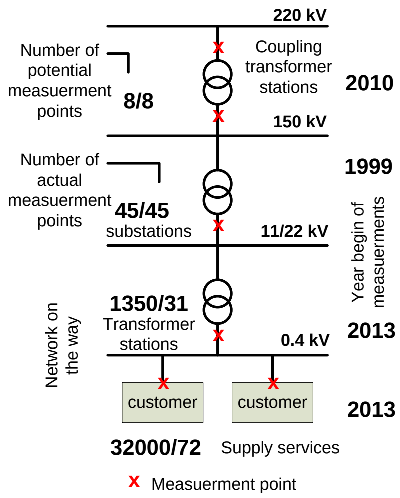

Figure 1: Planned and actual PQ-measurement points in the network of ewz.

Three years (2009-11) of data have been analysed so far. Figure 2 shows the number of voltage events (< 90 % or > 110 % of the nominal voltage, duration <= 60 sec) for all 45 medium voltage points for the year 2009 (each substation 3 instruments). An index, called SARFI (System Average RMS Variation Frequency Index), is introduced. The SARFI-X counting the number of events below 90 % or above 110 % of the nominal voltage is called $SARFI_{90}$ or $SARFI_{110}$ respectively. Other SARFI-X (80, 70, 50 or 10 % of nominal voltage) can also be evaluated. The values are normalized to one year with respect to the actual operating time of the particular transformer. If no value is indicated the reason could be either that no data were available or that the transformer was in a non-operating state (standby). The last column in Figure 2 shows an average of about 20 voltage dips during the year 2009.

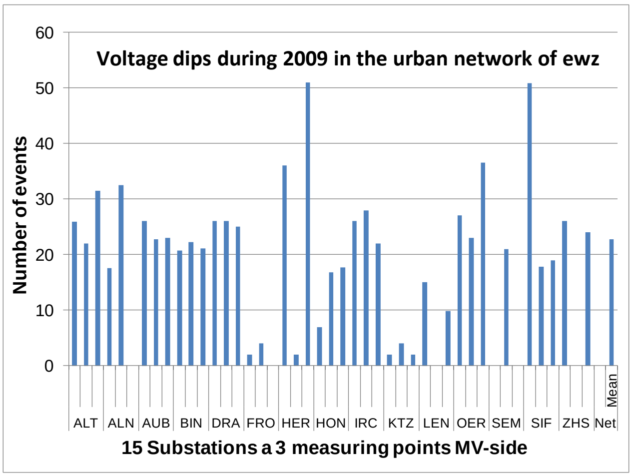

Figure 2: Measured voltage dips during 2009. The numbers of $SARFI_{90}$ are given.

Figure 3 shows an example of voltage dips or swells for one substation (SIF) within the period 2009-11. It is common to aggregate the dips or swells over one minute measurement time [4] to form an event, which constitutes of a pair of values, namely the lowest magnitude of a dip or the highest one for a swell during that particular minute and the corresponding duration. One minute was also chosen for the following analysis.

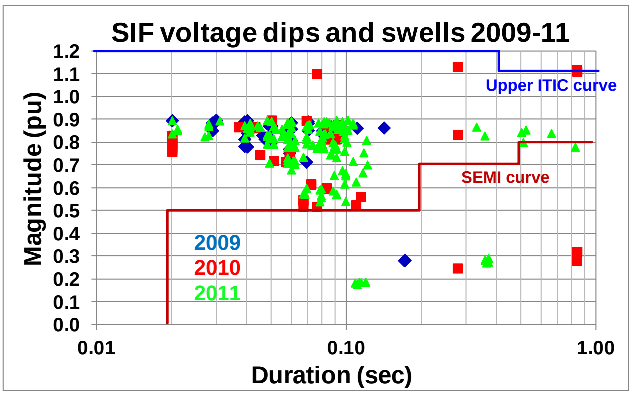

Figure 3: Magnitude-duration scatter plot of voltage dips and swells during three years of measurement for substation SIF.

$SARFI_{curve}$ is an index, which represents the number or rate of events below (voltage sag) or above (voltage swell) an industry immunity curve as CBEMA, ITIC and SEMI. The ITIC upper curve and the SEMI curve are indicated in Figure 3. For customer cost calculations, the dips below the SEMI curve and the swells above the ITIC upper curve are considered. Previous analysis of PQ [4] has shown that "the ITIC lower curve generally defines a clear boundary between voltage dips that result in plant equipment trips and those that do not." In order to not overestimate the costs the SEMI curve is used as lower curve, as it counts even less events than the ITIC lower curve (Table 1). Those events have the potential to disturb the function of many sensitive apparatus in the daily world of business; therefore customer costs can be expected.

In the third line Table 1 all counts of $SARFI_{90}$ are displayed without any restrictions (e.g. timely aggregation). Then follow the $SARFI_{curve}$ counts and the percentage of the total of measured dips or swells for all three measurement years with respect to all five known industry immunity curves, namely CBEMA, ITIC and SEMI.
Two scenarios are commonly used to count the number of major PQ events: 1) In between two events (one minute aggregated) 5 minutes have to pass before another event at the same measurement point is counted. In case of a failure it might take some minutes to restart the particular apparatus which failed. A further event after more than 5 minutes could lead to another failure which could possibly increase the damage. 2) Only one event is counted per day and measurement point. Usually there are not many independent dips or swells during one day. Therefore, to make it simpler, only one pair of data per day is taken into account: The deepest magnitude of the daily set and the corresponding duration. In this paper the approach 2 is applied (Table 1).

Number and percentage of "SARFI curve relevant" voltage sags and swells. One event per day and measurement point is counted.						
Year	2009		2010		2011	
total number without timely aggregation		727		818		2613
Typ of curve	SARFI curve	% of total	SARFI curve	% of total	SARFI curve	% of total
CBEMA high	5	0.69	24	2.93	11	0.42
CBEMA low	75	10.32	114	13.94	343	13.13
ITIC high	3	0.41	7	0.86	4	0.15
ITIC low	40	5.50	76	9.29	227	8.69
SEMI	37	5.09	7	0.86	91	3.48

Table 1: Number of counts of $SARFI_{curve}$ and the percentage on the total of major dips, resp. swells using data from all 45 points.

Differences from year to year are noticeable (e.g. lower immunity curves) indicating that only one year of measurement is not enough to be representative for a particular distribution network. Continuous information is important.

ESTIMATION OF CUSTOMER COSTS

In [5] (a guide for the management of the economics of power quality) it is considered that "in many cases it is the cost of consequences of poor power quality which are set against the cost of improving the network, whereas the correct approach is to compare the costs of options to mitigate the consequences against the cost of accepting the consequences." Here we focus on analyzing the consequences of major dips or swells, not trying to look for options to mitigate it. An estimation of total yearly costs, which customers have to expect, is the goal of this section. The two left hand columns of Table 2 present the categories of branches already used by ewz in the existing model to calculate customer costs during an outage (> 1 min) [2]; an example for respective branches is given in the third column. Costs per kW in case of a major voltage event have been found for many branches in the literature [References available from the authors]. The extracted value in CHF/MW is given in the right hand column of Table 2.

Customer costs per lost MW during voltage sag or swell			
Category	Description	Example	CHF/MW
1	Private households		385
2	Industry and Trade		
2.1	Small industry	Metall-, Electronic goods,	4566
2.2	Trade	Print Business	3234
2.3	Textile products		4389
2.4	Large industry	Steel work, Car industry	not used
2.5	Construction	Building business	4171
2.6	Manufacturing	Continuous production, Pharma industry	5159
3	Commercial services		
3.1	General services	Food stores, Hotels	3958
3.2	Financel services	Banks	3080
3.3	Insurance		3080
3.4	Real estate		3080
3.5	Wholesale trade	Large stores, Trading	3080
4	Social services		
4.1	Infrastructure	Communication, Transportation	1196
4.2	Government	Administration	1196
4.3	Educational services	Schools	1196
4.4	Health services	Hospital, Medical care	3080
5	Agriculture	Farms, Garden Centre	1694

Table 2: Considered branches and the corresponding costs of major voltage sags and swells. 1 EUR = 1.54 CHF (average of the period 2004-10, during which literature was available).

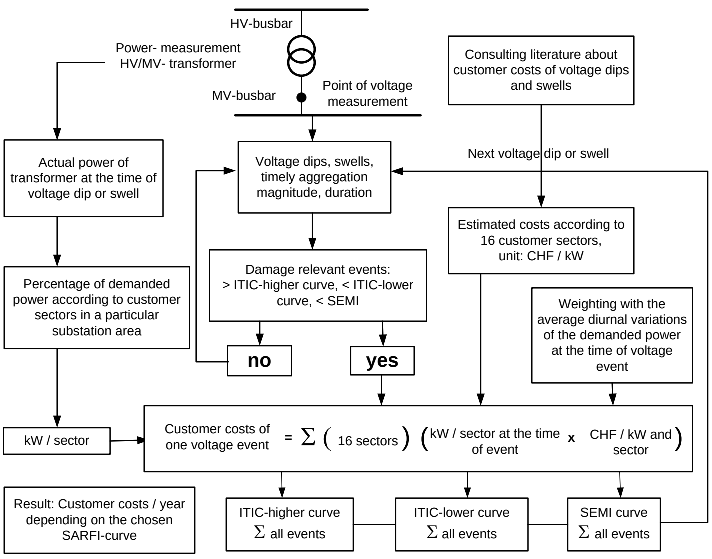

Figure 4: Elements of the PQ cost model to estimate the customer costs according to 16 different sectors of business.

The customer costs will be estimated with the help of a cost-model, illustrated in Figure 4. The model calculates the economic damage which customers (e.g. private households, services, industry, and public services) suffer because of power loss caused by voltage dips or swells. The model takes the unsupplied power, the time of the major dip or swell and the particular substation of interest as input. Costs per MW according to 16 sectors are used as well as the particular percentage of non-available power for each sector. A weighting function (% of daily variation of the maximum daily power demand) is considered. The actual power demand at the moment of the voltage event will be divided into the individual demand of each branch. Only dips or swells which are below or above a particular immunity curve (CBEMA, ITIC, SEMI) are considered.

RESULTS

The cost of each major voltage disturbance, obtained by the PQ cost model, was compared with the result of the outage cost model [2] using the same input data. If a duration of 3 minutes is taken for the outage model then the regression of the pairs of results is almost one to one and the correlation coefficient accordingly high (Figure 5). Three minutes seem to be a plausible time span to restart computers or other apparatus on the average after a major voltage event. This result seems to confirm the usefulness of the PQ-model.

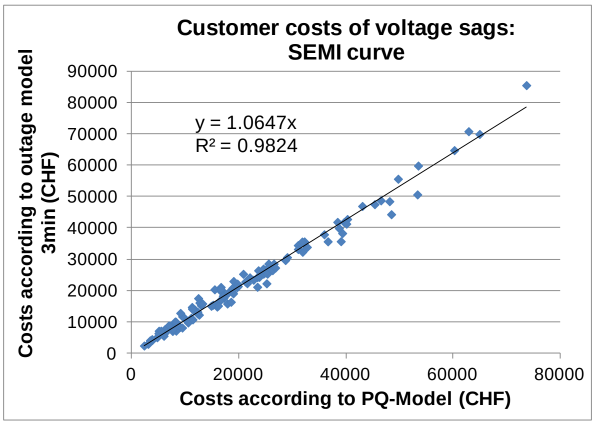

Figure 5: Comparison of the results of two customer costs calculation models.

If the above statement is true then calculations can be made for the whole year to get an idea of the possible economic effect of the major voltage events in the whole distribution network of ewz. Table 3 shows some results for all five classical immunity curves, for three years (2009-11), the resulting average and 5 scenarios, namely: 1) all customers, no protection against voltage disturbances, 2) all customers, 25 % with protection, 3) customers without private households, 25 % with protection, 4) ITIC high and SEMI, all customers, no protection, 5) ITIC high and SEMI, without private households, 25 % with protection. Scenario

4 and 5 are the most strict concerning the number of major voltage dips. Another constraint for the calculation was that only the major event was taken per day. It is evident that the resulting amount can considerably vary depending on the type of curve applied. For the most strict scenarios (4 and 5) the total economic damage for the regarded customers would be about 1 Million CHF or with protection 0.83 Million CHF.

Year	2009	2010	2011	Average 2009-11
Typ of curve	1) All customers, no protection			
CBEMA high	162	543	167	291
CBEMA low	2181	1504	6281	3322
ITIC high	130	240	73	148
ITIC low	1025	1195	3584	1935
SEMI	946	159	1740	948
	2) 25 % of the customer have protection			
CBEMA high	122	407	125	218
CBEMA low	1636	1128	4711	2492
ITIC high	98	180	55	111
ITIC low	769	896	2688	1451
SEMI	710	119	1305	711
	3) 25 % have protection, without private households			
CBEMA high	122	413	148	228
CBEMA low	1658	1142	4771	2524
ITIC high	98	183	56	112
ITIC low	779	908	2725	1470
SEMI	719	121	1325	722
ITIC high and SEMI	4) All customers, no protection			
	1076	399	1813	1096
ITIC high and SEMI	5) 25 % have protection, without private households			
	817	304	1380	834

Table 3: Comparison of customer costs (1000 CHF) according to curve type. Only one major voltage sag or swell per day and per measurement point is considered (1 EUR = 1.54 CHF, average 2004-10).

A comparison with results from other countries is displayed in Table 4. The costs are shown per inhabitant [6]. The upper part of Table 4 depicts the numbers for Norway, Sweden and Italy and the lower part the numbers from ewz (urban Switzerland). One has to consider, that for Sweden and Italy the numbers are given for both dips and interruptions, therefore, for ewz all three possibilities (dips, interruption, dips and interruption) are shown. The costs for the ewz network are generally slightly lower than the ones from the other countries but still more or less in the same range. One has to be aware that a country value shows a mixture of urban, semi-urban and rural values. ewz on the contrary is a completely urban network.

Costs / inhabitant (according to CEER 4th Benchmarking Report)			
Country	Year	Kind of costs	Estimated annual costs / inhabitant (EUR)
Norway	2002	Dips	3 - 11
Sweden	2003	Dips and Interruptions	16
Italy	2006	Dips and Interruptions	8 - 13
In comparison (this study)			
ewz	2009-11	Dips	1.6 - 6.1
	2009-11	Interruptions	3.3
	2009-11	Dips and Interruptions	4.9 - 9.4

Table 4: Comparison of the estimated costs per inhabitant for three countries versus the results of ewz. Numbers are given for dips alone, resp. dips and interruptions together.

CONCLUSIONS

Voltage disturbances move into the focus of customers and regulators because of the increasing number of sensitive electronic apparatus in use and to system operators in connection with increasing decentralized generation.
Therefore, to control voltage quality, ewz is installing a network on all voltage levels and at customer sites, which is intended to represent the whole network. The knowledge about the number of major voltage events, allows the estimation of total customer costs.
The results show that the calculated costs for the customers of ewz are in the range of results published in the 4th CEER benchmark report [6]. In the future besides costs, ewz would like to extract a SARFI-System index to characterize its own network and to compare with other networks. The PQ measurement network in conjunction with the cost-model forms the basis for an efficient PQ management.

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