SCHEDULED INTERRUPTIONS IN AN URBAN NETWORK AND THEIR RISK FOR SUBSTANTIAL CUSTOMER COSTS IN A FOLLOW-UP OUTAGE: A CONTRIBUTION TO MITIGATE ECONOMIC LOSSES

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ABSTRACT

Urban HV- and MV-distribution networks are usually designed to fulfill the (n-1)-rule under normal state operation. During a planned interruption, because of maintenance, repair or renewal work, the redundancy in case of a coincidental outage might not be given anymore. The risk of such a coincidence is small but if an outage occurs the economic loss for the affected customers can be substantial. Estimations of direct customer costs are made to determine the loss which has to be expected because of a follow-up outage.

INTRODUCTION

The "Elektrizitätswerk der Stadt Zürich" (ewz) is an urban distribution network operator (15 HV/MV-substations, 83 km 150 kV-cables, resp. 72 km overhead lines, 800 MV/LV-stations, 830 km MV-cables, 260'000 LV- connections, 3000 GWh energy consumption). Beside reliability parameters like SAIDI and SAIFI, ewz routinely monitors also the customer costs for unplanned outages. So far no estimations of customer costs have been made for planned interruption in the case of a follow-up outage. In the future ewz would like to rank the relevance of a planned shutdown on the basis of economic losses caused by planned switching in the network. Therefore, the aim of the paper is to show the process and to get some conclusions about the significance of this task. In the following, the 150 kV-network will be considered although the MV-network has the same priority for ewz. The 150 kV-network of the city of Zürich as well as the HV/MV-substations (in the following SUB) are depicted in Figure 1.

In the article typical switching constellations are presented, an overview of customer costs calculation is given and by means of an example substation the process to obtain the customer costs in case of an outage is shown. Afterwards all substations in the network of ewz are compared. Shutdown scenarios are presented and their individual risks are discussed.

NETWORK AND SHUTDOWN SCENARIOS

An electric distribution network is a dynamic structure, that is always under modification. Maintenance, repair, replacement of components, construction engineering etc. call for continuous work. Therefore, project engineers need to repeatedly apply for safety disconnection or switching bans. Because of numerous projects during the year the standard configuration of the network is seldom in operation, usually at weekends also to discover any damaged cables, caused by civil engineering work. Thus planned switching belongs to the daily duties of an operation center. Some of the non-standard configurations still hold the (n-1)-rule (for the 150 kV-network), some not anymore. In the latter case a certain risk is given that an unplanned interruption could happen. This involves some interruption costs which the customers have to bear.

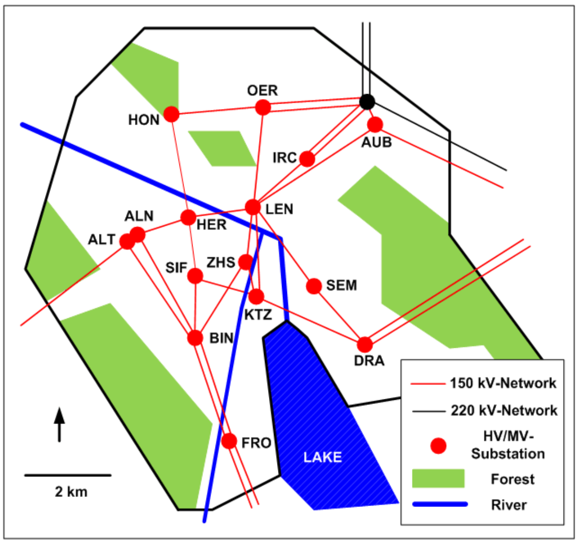

Figure 1: 150 kV-network of ewz in the city of Zürich. Circles mark HV/MV-substations. The abbreviations of the substation's name will be used in the following.

The following non-standard situations are frequently observed as a result of planned switching:

1) Revision in a substation, half of the SUB is not available, re-supply longer than 4 hours.
2) A SUB is only fed by one radial-line connection, further links have a safety shutdown, a re-supply within one hour.
3) A SUB is only fed by one radial-line connection, further links have a switching ban with a prepared emergency switching program (re-supply about 4-8 hours).
4) Two SUBs are fed by one radial-line connection from the same SUB, a re-supply is possible within one hour.
5) Complete disconnection of one SUB from the network, failures possible during extended switching programs (re-supply upon situation).

ESTIMATION OF DIRECT CUSTOMER COSTS

The customer costs will be estimated with the help of a cost-model [1, 2], according to the particular scenario. The model calculates the direct economic damage which customers (e.g. private households, services, industry, public services) suffer because of power loss. Indirect costs are not considered (e.g. employee is late in office because of public traffic problems). The model examines the un-supplied power, the duration and time of the outage and the particular substation of interest as an input (Figure 2).
Cost functions according to 15 sectors are used as well as the particular percentage of not-available power. Weighting functions (% of maximum power demand over the day) according to the time of day, day of the week and the season are considered. In case of an interruption the not-availability of power will be a key-value for the computation, therefore the actual power demand at the moment of the outage will be divided into the individual demands of the branches.

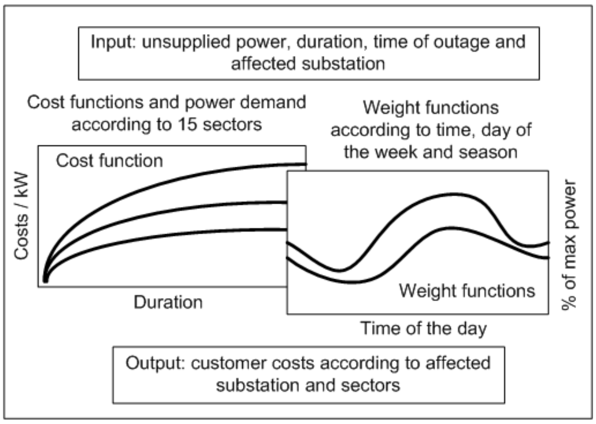

Figure 2: Scheme of the customer cost model.

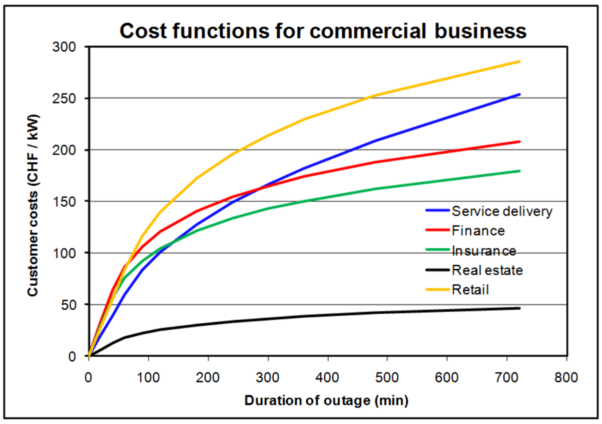

Figure 3: Average cost functions for business branches. The costs are given in CHF (1 CHF, around 0.7 EUR).

Figure 3 shows the costs functions [3, 4] for the commercial branches, which are established using customer surveys from literature (three cost functions are usually computed, an upper and lower curve of the business costs and its average). They display the customer costs per kW lost power depending on the duration of the outage. Important is the retail business, where selling of goods is usually not possible anymore without electricity. The output of the model is the total cost for the SUB-domain and also for the individual branches (Figure 2).

COST EVALUATION EXAMPLE: SUB "BIN"

Five different daily power parameters are used for each of the 15 SUBs for the cost calculations, which describe the power demand over the year 2009: 1) average of daily minimum, 2) average of daily average, 3) the highest daily average, 4) average of daily maximum and 5) the highest daily maximum. In Figure 4 the three curves describe the minimum, average and maximum daily power demand during the year 2009 for SUB "BIN". The straight lines are the above mentioned averages and the two highest values are marked with a circle.

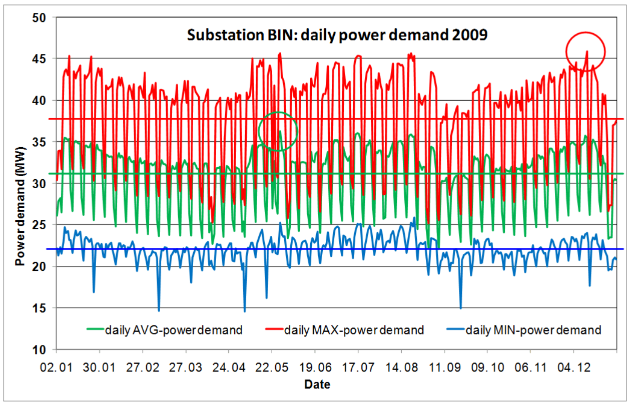

Figure 4: Time-series of daily minimum, average and maximum of requested power at SUB "BIN". Highest values are marked.

The results of the cost calculations according to the mentioned five power demand parameters and for different durations of interruption are depicted in Figure 5. The time of day is chosen to be midday, when power request is more or less at its peak. The costs are given in Mio. CHF (1 CHF is about 0.7 EUR).

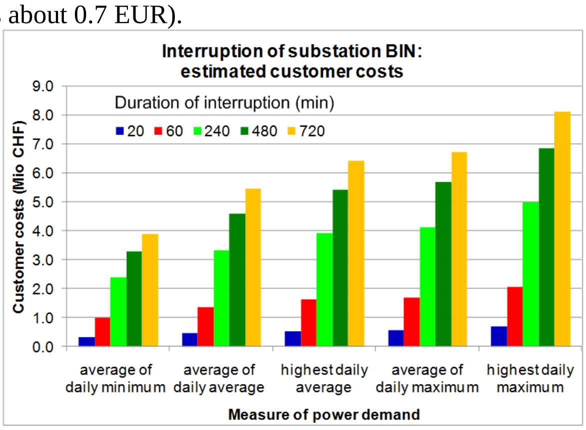

Figure 5: Customer costs for different power input and durations for SUB "BIN".

Figure 5 shows that the costs depend on the chosen power input. However differences are small between the histograms 2, 3 and 4. Since the power demand differs during a day, it is clear that the costs also change during the day, depending at what time the outage will occur.
Therefore, calculations were made for different points of time during a weekday. Figure 6 displays the results. Around 4 a.m. we would have a minimum damage in case of a follow-up outage.

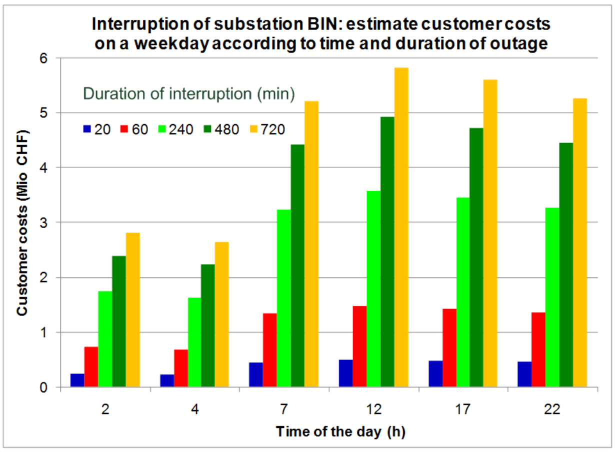

Figure 6: Estimated customer costs according to the point of time of the event and the duration of the outage for SUB "BIN". The power variable "average of daily average" is used for computation.

COMPARISON OF ALL SUBSTATIONS

Analogous cost calculations were made for all 15 SUB-domains in the network. For that the individual power demand of each SUB was evaluated. Table 1 lists the particular values for the five power-variables. Large variations among the domains can be observed.

Daily power demand (MW) of 15 HV/MV-substations during the year 2009					
Substation	Daily minimum	Daily average		Daily maximum	
	Average	Average	Maximum	Average	Maximum
ALN	14	18	21	21	27
ALT	18	27	33	35	53
AUB	3	10	22	16	29
BIN	22	31	36	38	46
DRA	18	26	32	33	40
FRO	11	17	20	21	25
HER	7	11	20	15	29
HON	12	19	28	24	36
IRC	17	24	30	30	41
KTZ	17	31	41	43	59
LEN	16	26	39	34	51
OER	12	20	36	27	50
SEM	5	10	15	14	18
SIF	11	17	22	22	28
ZHS	12	20	25	27	36

Table 1: Daily power demand (MW) of 15 substation-domains in the network of ewz, showing 5 different values, measured over the year 2009.

The values from Table 1 are used as part of the input into the cost model. Table 2 shows the results of the computation for two of the above variables (average of daily average, highest daily maximum). Time of the event is at 12 a.m. on a winter weekday and for an outage-duration of 60, resp. 240 min. The outcome looks quite different among most of the SUB-domains, strongly depending on the percentage of the branches within the domain and on the total power demand.

Customer interruption costs (Mio CHF)					
Measure of power		Average of daily average		Highest daily maximum	
Duration of outage (min)		60	240	60	240
Substation	ALN	0.8	1.8	1.2	2.8
	ALT	1.1	2.7	2.1	5.2
	AUB	0.4	0.9	1.0	2.6
	BIN	1.4	3.3	2.1	5.0
	DRA	1.0	2.4	1.5	3.7
	FRO	0.6	1.6	1.0	2.3
	HER	0.6	1.3	1.5	3.5
	HON	0.6	1.6	1.2	3.1
	IRC	0.8	2.0	1.4	3.5
	KTZ	2.1	4.4	4.0	8.5
	LEN	1.1	2.7	2.1	5.2
	OER	0.6	1.7	1.6	4.3
	SEM	0.4	1.0	0.8	1.9
	SIF	0.6	1.6	1.0	2.6
	ZHS	1.1	2.6	2.0	4.5

Table 2: Results of the cost model calculations for two power demand measures and two durations of outage for all HV/MV-substations of the ewz-network. The customer costs are given in Mio CHF.

THE ECONOMIC RISKS

The question arises: How often does a follow-up outage of a SUB happen and what is the amount of damage which has to be taken into account by the company each year?
As an example we consider a worst case scenario and use the "highest daily maximum" power demand for the customer cost calculations. Safety shutdown switching is demanded by project engineers in such a way that two SUBs are in one radial-line connection (case number 4). Figure 7 displays schematically the corresponding scenario as well as the frequency of an outage per year for the SUB (about 0.064) and the frequency (malfunction and outage) for a 150 kV-cable connection of a length of 2.5 to 3 km (about 0.032).

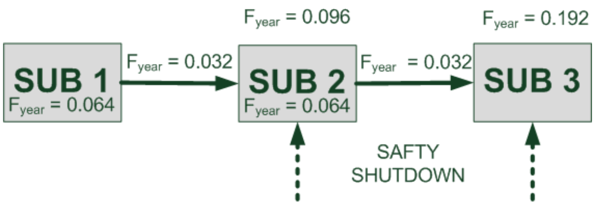

Figure 7: Scheme of one of the possible shut down scenarios. The frequency of an unplanned interruption per year for a substation or for a cable-connection is given. The numbers above show the combined frequency for SUB2, resp. for SUB3.

Using the above values, the frequency of an outage in SUB2 (example "ALT+ALN", in this context "ALT and ALN" are considered as one SUB, because they are in the same location) is 0.096 and for SUB3 ("HER") accordingly 0.192 (repetition periods about 10, resp. 5 years). In case of a fault in SUB1 (example "BIN") or the connection SUB1 - SUB2 ("BIN" - "ALT+ALN") the restoration of the supply should not exceed one hour, i.e. the safety shutdown cable connection should be reversed within the given time. Hence, the customer costs are calculated for a restoration time of one hour. Table 2 shows that the one hour outage-costs for the domains "ALT+ALN" would be approximately 3.3 Mio CHF, for "HER" 1.5 Mio CHF respectively.
The internal statistics for two years (2009, 2010) exhibits that a safety shutdown of cable-connections last on the average 9 working-days (spread between 2 to 33 days for single events). The weekends are not counted because the safety disconnections are usually restored during weekend. Considering our example of Figure 7, the probability to fail during the 9 days for SUB2 is 0.096/365*9 days = 0.00237, resp. for SUB3: 0.192/365*9 = 0.00473. Therefore, the economic risk would be about 7'800 CHF for SUB2 (3.3 Mio * 0.00237), resp. for SUB3 approximately 7'100 CHF, on the total nearly 15'000 CHF per year. The longer the safety shutdown the greater the probability that a particular outage will happen. If we take the longest duration of 33 days for the above scenario, the yearly economic loss would be an estimated 55'000 CHF.
According to the above mentioned statistics, the setting is expected 6 times a year with an average risk of 11'000 CHF per case. Hence, the total operational risk for the enterprise is nearly 70'000 CHF per year. If the unplanned interruption happens in the early morning hours the financial risk would be about half the price (see Figure 6 costs according to the time of day). If the outage occurs on the weekend, the customer costs would be less. If the restoration time is 2 or 4 hours the cost will rise according to the cost function in Figure 3. Table 2 also shows the event-costs for a 4-hour outage. Instead of 3.3, resp. 1.5 Mio CHF the input values would be 8, resp. 3.5 Mio CHF. Additional costs per year arise from all the other possible scenarios, e.g. half of the SUB is not available because of revision work e.g. of a transformator (case 1) or one SUB is situated in a radial line connection (case 2). The outcome for case 1 and 2 is on the average 20'000 CHF per event, totaling with about 9 cases (5, resp. 4) per year to an amount of 180'000 CHF.

CONCLUSIONS

An outage of a SUB can have a remarkable effect on the economy within its domain. For instance in the business district of the city ("KTZ") an one hour outage can cause an estimated 2.1 Mio CHF direct loss. Indirect costs are so far difficult to establish but could be in the same order of magnitude or even more. Beside the financel losses, maybe more important, the company's image will suffer and the city council as well as the regulator (not yet in Switzerland) will ask unpleasant questions. Since the economy takes a resilient power supply for granted or considers it as a location advantage and to avoid bad media presence, ewz has included the possible economical impact of a planned interruption into its decision process: the larger the economical damage of a possible outage, the higher the decision in the company's hierarchy. This includes also the responsibility to interrupt maintenance work or setting other priorities. Examples are:
In scenario 1, the network engineer is responsible to allow the shutdown of components in a SUB. For scenario 3, the operation center has to permit the switching and for scenario 5 the chief of the operation and maintenance center is in charge. These clear responsibilities enable the discussion of the project in a larger context, thinking about alternatives or preventive measures, e.g. it is planned to expand the 150 kV-network in such a way to avoid infringing the (n-1)-criteria, e.g. each SUB is connected to at least three 150 kV-cables.
Since the customer costs strongly depend on the power demand during the day (e.g. for commercial business), the possibility to mitigate the costs is given in shifting maintenance or repair works into the early morning of a working day where the power loss is less than during business hours. Also the weekend could be an alternative. This is imaginable for cases with safety shutdowns. For power-sensitive customers individual emergency schemes are prepared.
In the future the same evaluation is planned for the MV-network. This enables the calculation of the total amount of customer costs (HV and MV), the company has to expect from planned switching programs. Possible mitigation concepts may then be evaluated.

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