LOAD LOSS EVALUATION FOR DISTRIBUTION TRANSFORMERS IN NETWORKS WITH LARGE AMOUNTS OF PHOTOVOLTAIC GENERATION – A CASE STUDY USING AMR DATA.

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ABSTRACT

The impact of photovoltaic (PV) generation to the evaluation of load losses have been analysed in this paper using data from AMR meters.

PV generation has been simulated using sun radiation data together with AMR data for 14 low voltage networks. These networks have different characteristics when it comes to number of customers, types of customers and type of heating.

The results show that PV generation in networks with district heating and industries gives the biggest reductions in loss utilisation time, up to 20%. Smaller reductions have been obtained in other networks mainly in the range 4-12%. These differences are however in the same range as the difference between using classical approach to determine the loss utilisation time and AMR approach.

The low impact to loss utilisation time doesn't motivate a specific loss evaluation for networks with large amount of PV generation.

Keywords: Loss evaluation, distribution transformers, photovoltaic generation

BACKGROUND

Vattenfall Distribution Sweden has since 2003 built up an AMR/AMI-platform including remote controlled smart meters. The main reason for the installation has been to automate the meter value collection process and support the customer with bills based on actual consumption. Based on this, Vattenfall has taken the next step and uses the AMR information in new areas.

Project Area Measurement

Project Area Measurement (PAM) is a project initiated within Vattenfall in order to investigate how smart metering data could be used to improve network analysis in order to optimize the asset management process and hopefully reduce the investment costs. Within the scope of the project, meters have been installed in 14 secondary substations and hourly meter values have been collected from these meters and also from all other meters in the same low voltage network. The analysis conducted in this paper only uses the hourly meter data collected from the secondary substations.

Studied time period

The time period that have been chosen for the analysis is May 25th, 2010 – May 24th, 2011.

STUDIED LV-NETWORKS

The studied low voltage (LV) networks are listed in table 1 together with number of customers and characteristic type of heating. Networks without characteristic heating can be assumed to have a mix of different types of heating.

Table 1. Studied LV-networks

Network name	Cust-omers	Heat-ing	Load category
Bången	20	EH	Residiential, farms
Riekkola	25		Residential, industry
Tjärn	12		Residiential, farms
Huuki	23		Residiential, cottages, farms
Hackhyttan	7		Residiential, farms
Juringe väg	53	EH	Residential, farms
Ekenäs hamn	6		Residiential, farms
Tjärnstigen	41	EH	Residiential
Slakthuset	18	DH	Industry, residential
Fornby	67	HP	Townhouses
Brantingstorg	208	DH	Residential, stores, schools
Mältargatan	7	DH	Ofices, workshops
Nåntuna villastad	74	DH	Residential, district heating
Markegångs-vägen	188	EH	Townhouses

Where:
EH: Electric heating
DH District heating
HP Heat pumps

AMR meters have been installed in the 14 secondary substations on the low voltage side of the transformer as illustrated below.

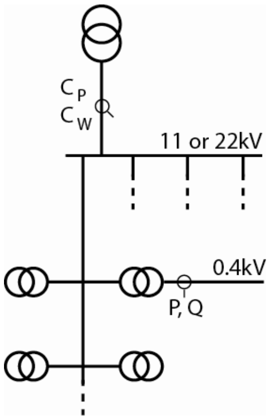

Figure 2. Schematic illustration of measurement points

The charge for annual energy (C_W) and peak power (C_P) are assumed to be based on measurements on the medium voltage side as illsutrated above.

LOSS EVALUATION AND PROCUREMENT

The loss evaluation is used by transformer designers to optimize the use of core material in transformers. The material cost is optimized against cost of future losses.

TCO approach in transformer procurement

The proposed method for selecting transformers with the lowest total cost of ownership (TCO) is described in European standard EN 50464-1 [1]. According to this method, the total cost of ownership is defined as:

$$C_C = C_T + A \cdot P_0 + B \cdot P_k \quad (1)$$

Where:

C_C Total cost of ownership (capitalised cost)
C_T Purchase cost of transformer
A Value indicated by the purchaser in the enquiry expressed in local currency per watt. (e.g. €/W) corresponding to no load losses.
P_0 Guaranteed no load losses (W)
B Value indicated by the purchaser in the enquiry expressed in local currency per watt. (e.g. €/W) corresponding to no load losses.
P_k Guaranteed load losses (W)

The coefficients A and B are determined by equations (2) and (3).

$$A = C_{npv}\left(C_P + 8760 C_W\right) \quad (2)$$

$$B = C_{npv} D^2 \left(C_P + 8760 C_W LLF\right) \quad (3)$$

Where:

C_{NPV} Net present value coefficient (pu)
C_P Annual charge per kW of maximum demand (€/kW)
C_W Energy cost for losses (€/kWh)
D Demand factor
LLF Load loss factor

Net present value coefficient

The net present value (NPV) coefficient is obtained from company specific interest rates, book life of transformer and future electricity price predictions.

Demand factor

The demand factor, D, gives the difference between the maximum power demand of actual load and the rated transformer power. The maximum power demand from loads can be obtained from historical measurements or by calculations.

$$D = \frac{S_{\max}}{S_n} \quad (4)$$

Where:

D Demand factor (pu)
S_{max} Maximum power demand from loads (kW)
S_n Transformer rated power (kW)

Classic approach to determine load loss factor

The transformer load characteristics are used to determine coefficient B in equation (1). The loss factor and transformer peak load can represent the load characteristics when determining B. As a general practice [3], the loss factor is determined as (2).

$$LLF = 0.15\frac{P_{average}}{P_{peak}} + \left(0.85\frac{P_{average}}{P_{peak}}\right)^2 \quad (5)$$

Where :

LF Load loss factor
$P_{average}$ Average load
P_{peak} Peak load

AMR approach to determine load loss factor

The AMR approach for determination of the loss factor uses annual loss energy W_l as expressed in (6).

$$W_l = \int_0^T P_l dt \quad (6)$$

Further on, P_l can be written as:

$$P_l = R\left(\frac{S}{U}\right)^2 = R\left(\frac{S_{\max}}{U}\right)^2 \left(\frac{S}{S_{\max}}\right)^2 \quad (7)$$

This gives the final expression that has been used in the AMR approach to determine load loss factor:

$$W_l = P_l \int_0^T \left(\frac{S}{S_{\max}}\right)^2 dt \quad (8)$$

Where:

W_l annual losses (Wh)
P_l Active losses at time $0 \le t \le T$ (W)
R Real part of transformer impedance

S	Load at time $0 \le t \le T$ (VA)
S_{max}	Max load (W)
U	Voltage (V)

PHOTOVOLTAIC LOAD FLOW MODEL

The impact of PV generation has been studied using a simplified load flow model combined with sun radiation data.

Photovoltaic generation model

Calculations of load flow and losses have been done using a simplified PV model. The model is based on the Matlab code in [4] and uses direct sunlight radiation as input and scaled in accordance to the desired PV penetration level. The model assumes that PV cells are mounted towards south with an angle of 30 degrees from the horizontal plane.

Sunlight irradiance data used for PV modelling

Data used for modelling PV generation have been from the STRÅNG model. This model produces instantaneous fields of global radiation, photosynthetically active radiation, UV radiation (CIE weighted) and direct radiation together with sunshine duration at a horizontal resolution of about 11 x 11 km and a temporal resolution of one hour.

STRÅNG data used here are from the Swedish Meteorological and Hydrological Institute (SMHI) [5], and were produced with support from the Swedish Radiation Protection Authority and the Swedish Environmental Agency.

The geographic positions that were used when obtaining STRÅNG data are listed below.

Table 2. Geographic positions used for STRÅNG data

Network name	Municipality	Lat.	Long.
Bången	Uddevalla	58.20	11.56
Riekkola	Haparanda	65.49	24.07
Tjärn	Örnsköldsvik	63.17	18.42
Huuki	Pajala	67.12	23.21
Hackhyttan	Nyköping	58.45	16.59
Juringe väg	Huddinge	59.14	17.58
Ekenäs hamn	Säffle	59.07	12.55
Tjärnstigen	Tyresö	59.14	18.13
Slakthuset	Uppsala	59.51	17.38
Fornby	Uppsala	59.51	17.38
Brantingstorg	Uppsala	59.51	17.38
Mältargatan	Uppsala	59.51	17.38
Nåntuna villastad	Uppsala	59.51	17.38
Markegångsvägen	Uppsala	59.51	17.38

PV penetration level

PV penetration level has been used as a measure of the installed PV generation. The definition used in this paper is the ratio between installed PV generation and max load without PV generation.

$$PL = \frac{\sum P_{PV\_rated}}{\max\left(\sum P_{Loads}\right)} \qquad (9)$$

Where :

PL	Penetration level (pu)
P_{PV_max}	Max output power from PV generation (kW)
P_{Loads}	Customer loads (kW)

RESULTS

Focus have been to compare the loss utilisation time between networks without PV generation and networks with different amounts of PV generation related to the maximum load.

Loss utilisation time – classic approach

The classical approach to determine the loss utilisation time (eq. 5) gives values according to the table below. As seen in the table, the classical approach gives lower values compared to the values calculated using AMR data.

Table 3. Calculated parameters without PV generation

Network name	P_{max} kW	T_{Load} h	$T_{Loss,1}$ h	$T_{Loss,2}$ h
Bången	114	3057	1229	1324
Riekkola	33	1784	530	693
Tjärn	49	2767	1046	1047
Huuki	56	3573	1589	1737
Hackhyttan	35	2488	884	893
Juringe väg	424	3129	1277	1422
Ekenäs hamn	33	3308	1399	1577
Tjärnstigen	237	3227	1343	1550
Slakthuset	749	3414	1474	1614
Fornby	455	2544	915	1021
Brantingstorg	463	4862	2679	2945
Mältargatan	553	3795	1757	2196
Nåntuna villastad	164	3462	1508	1605
Markegångsvägen	617	2944	1156	1314

Where :

S_n	Rated power of transformer
P_{max}	Maximum measured power
T_{Load}	Load utilisation time
$T_{Loss,1}$	Loss utilisation time, classic approach
$T_{Loss,2}$	Loss utilisation time, AMR approach

Loss utilisation time – AMR approach

The loss utilisation time have been calculated for different penetration levels.

Table 4. Calculated parameters with PV generation

Network name	Loss utilistation time (h) at different penetration levels (%)					
	0%	10%	25%	50%	75%	100%
Bången	1324	1266	1205	1171	1222	1357
Riekkola	693	670	661	714	852	1074
Tjärn	1047	1028	974	954	1022	1178
Huuki	1737	1670	1594	1537	1564	1675
Hackhyttan	893	851	812	815	902	1074
Juringe väg	1422	1371	1319	1300	1366	1517
Ekenäs hamn	1577	1513	1442	1392	1427	1546
Tjärnstigen	1550	1496	1440	1414	1473	1617
Slakthuset	1614	1535	1441	1352	1348	1431
Fornby	1021	993	976	1017	1119	1310
Brantingstorg	2945	2830	2680	2493	2388	2370
Mältargatan	2196	2093	1941	1757	1657	1643
Nåntuna villastad	1605	1542	1473	1425	1461	1583
Markegångsvägen	1314	1265	1217	1205	1277	1434

Differences between AMR- and classical approach

The classical approach as described in eq. 5 gives lower values compared to values obtained using AMR data. The difference corresponds approximately to a PV penetration level of 10-25% depending on load.

Comments to the results

For penetration levels above 25%, losses starts to increase for all networks except Brantingstorg and Mältargatan. These two networks are characterised by a large amount of daytime loads, such as industry, offices and schools.

CONCLUSIONS

The conclusion of the conducted study is the classical approach to loss evaluation gives sufficient accuracy for networks with PV generation connected.

To reduce the total cost of ownership, it is more important to focus on the demand factor (eq. 5) in order to achieve optimised loading and best efficiency.

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