ALLOCATION OF HARMONIC DISTORTION MARGINS AT THE POINT OF COMMON COUPLING

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ABSTRACT

In respect of harmonic distortion at the point of common coupling the current practise for companies connecting to the transmission and distribution network in the UK is to use the full available margin up to the planning or compatibility limits of the Engineering Recommendation G5/4.

The objective of this paper is to illustrate cases when customers with low load but high harmonic distortion use the full Total Harmonic Distortion margin so that the next customer is obliged to provide mitigation measures regardless of his contribution.

It discusses options for equal share in harmonic distortion contribution at the point of common coupling in order to create a workable relationship between the network operators and connected companies to deal with the harmonic distortion on a fair basis as part of the network long term planning.

1. INTRODUCTION

Transmission and distribution systems operate at nominal voltages within the tolerances prescribed by standards. Those margins are determined by the system operators and depend on various factors such as load variation, secondary equipment capabilities for voltage control, type of load, historical reasons etc. Generated voltage, which is of a sinusoidal character, is monitored at various points throughout the system for power quality purposes in order to ensure that the sine wave form is not distorted in magnitude and shape.

Power quality is the set of limits that allows electrical systems to function in a proper manner without significant loss of performance or service life. Harmonic distortion is one of the ways to cause poor quality. Level of harmonic distortion is directly linked to the power that supplies the load and the load's ability to function properly with that electric power. Without the suitable power quality the electrical equipment throughout the power system may malfunction, fail prematurely or not operate at all.

Harmonic distortion is caused by the load character for example by firing in AC to DC rectifiers, arc furnaces, etc. It is manifested on voltage in distorting the ideal sine-wave form. This distortion is theoretically analysed by Fourier analysis and presented in harmonic orders as multipliers of fundamental frequency (50Hz).

The most common points of power quality monitoring are where the systems couple i.e. Point of Common Coupling (PCC), which is usually between transmission and distribution systems and at connection of major customers such as transportation companies. This paper is focused on assessment of power quality at distribution transformer substations, where new load is being connected. Two cases have been analysed. The Base case is based on average system development with expected harmonic distortion. The second case is showing connection of relatively small load, but with much higher content of harmonic distortion that exceeds the harmonic distortion limits at the PCC.

The second case leaves no harmonic margin for the next consumers to connect which may not be harmonic polluters, however, would be forced, by present practice, to rectify the harmonic distortion increase at the PCC.

2. HARMONIC DISTORTION AT PCC

Harmonic distortion at PCC depends on the following:

a) Load
b) Type of load (equipment design)
c) Background harmonic level
d) Configuration (resonances depending on capacitive or inductive character of the elements in the network)
e) Fault level

The nature of load is one of the main contributors to the harmonic distortion. Typical example is rectifiers that convert AC to DC power to be used in traction metro systems. The distortion is directly proportional to the increase in load.

Harmonic distortion in the example of AC to DC rectification can be partly mitigated by design of the rectifier transformers from six to twelve pulse rectification at additional cost. Analysis on harmonic models would indicate what would be the reduction in harmonic contents. It is often the case that relatively smaller investment in 24 pulse rectifiers is less costly that installing the harmonic filters.

The system always has some presence of harmonics starting from the generators to the consumers. For this reason it is necessary to monitor by regular measuring present harmonics throughout the system. In case of connecting new load those measurements represent so called background harmonic distortion which must be taken into account as well.

Connection of larger subsystems to the main substations change the impedance calculated from the PCC. The impedance profile for various harmonics can indicate significant increase around the characteristic harmonics which is manifesting in resonant amplification. This effect is

mitigated by tuned harmonic filters i.e. combination of RLC elements calculated for each specific case.
Harmonic distortion is attenuated by increase in fault level at the PCC. Fault level at the PCC is generally increased by adding lines or cables and power transformers.

3. ANALYSIS OF LOAD CONNECTION AT PCC

There are companies that, when connecting at PCC, use all available harmonic headroom disproportionally to their connected load. For example typical combination of domestic and commercial load of 20MVA, if connected to substation of 240MVA firm capacity, would normally proportionally increase the harmonic distortion and there would be no need for mitigation.
However, companies that are usually associated with unbalanced loads, DC traction load or companies that have extensive internal cable network which, when connected to transmission or distribution network shift the impedance profile to create resonances, may be considered to benefit from this practise.
There are, therefore, cases when companies with average contribution of harmonics may be paying for harmonic distortion rectification if connecting to PCC where the limits have already been used up. They are obliged to rectify the Power Quality profile at PCC even if their contribution to the harmonic distortion is negligible compared to the load connected.
To illustrate the issue of unfair distortion share, two typical cases are presented in this paper, one with average harmonic distortion contribution named Base case and the other with extremely high contribution of harmonic distortion.

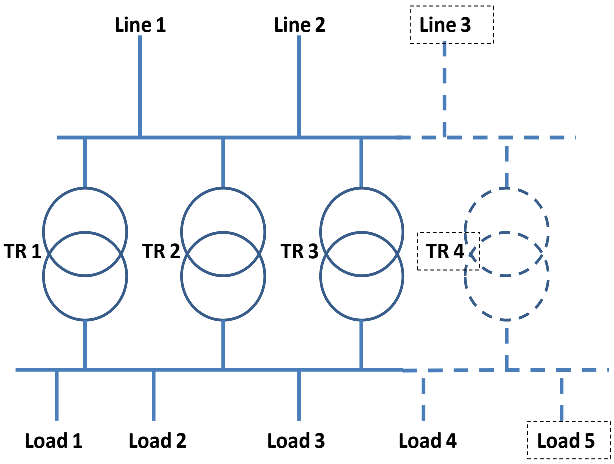

Figure 1

Figure 1 shows typical transmission / distribution substation which is over a period of its service being expanded from two in-feed lines and three Bulk Supply Point (BSP) power transformers with further extension by one line and a fourth transformer.
The expected load growth over a period of 40 years at this PCC is shown in Figure 2.

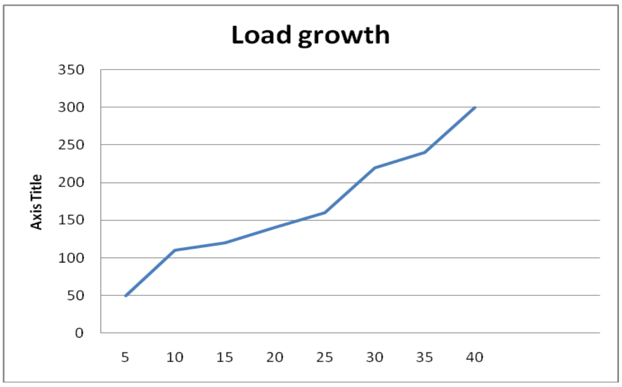

Figure 2

3.1 <u>Case 1</u>

For the loadgrowth in this substation the configuration in terms of number of infeed lines and transformers is shown in Table 1. For the load increase as indicated the Total Harmonic Distortion (THD) is shown in the last column of Table 1.

Years	Configuration	Load Increase	THD
5	2L+3T		0.35
10	2L+3T	60	0.77
15	2L+3T	10	0.84
20	2L+3T	20	0.98
25	2L+3T	20	1.12
30	3L+4T	60	0.616
35	3L+4T	20	0.672
40	3L+4T	60	0.84

Table 1

It can be noted that for the load increases in years to 5 to 25 the THD remins below the permitted level of 2% [1]. In year 30 the load approaches firm supply hence fourth transformer and third lines are installed which results in overall drop of THD due to the increased fault level.
For illustration purposes the installed transformer capacity versus the load increase is presented in Figure 3.

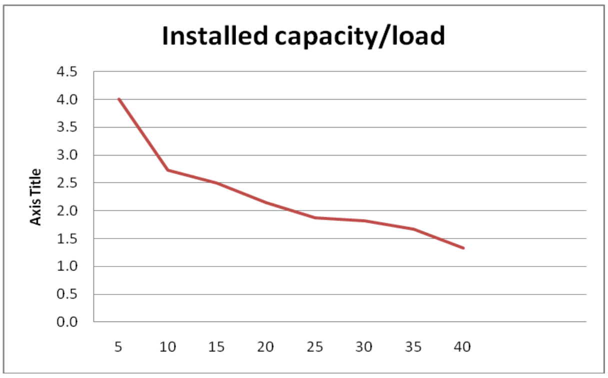

Figure 3

THD diagram for Case 1 as in THD column in Table 1 is shown in Figure 4.

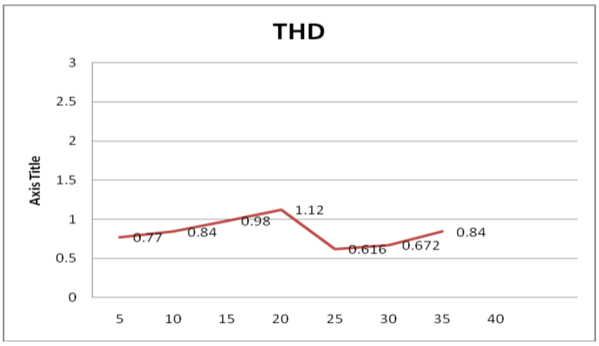

Figure 4

It is evident that for typical load the development of network with increase in fault levels is sufficient to mitigate the typical harmonic distortion associated with most of the load.

3.2 Case 2

This case assumes the same load growth and the same configuration as it is presented in Case 1. Therefore figures 2 and 3 apply for both cases. The difference in Case 2 is the increased THD in year 20 which is caused by relatively small load of 20MVA but with extremely high contribution of harmonics as it is shown in Table 2.

Years	Configuration	Load Increase	THD Excess
5	2L+2T		0.2
10	2L+3T	60	0.44
15	2L+3T	10	0.48
20	2L+3T	20	1.96
25	2L+3T	20	2.04
30	3L+4T	60	1.752
35	3L+4T	20	1.784
40	3L+4T	60	1.88

Table 2

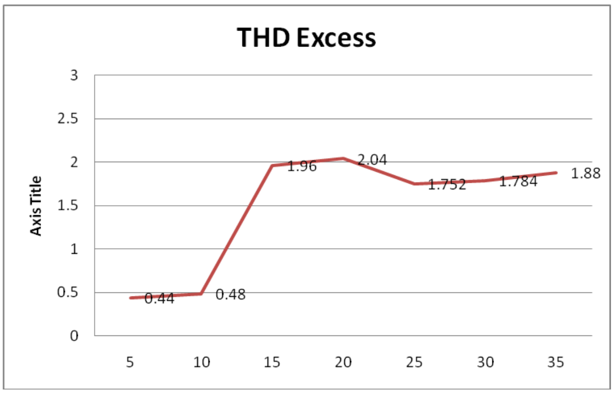

Figure 5

In Figure 5 it can be seen that in year 25 for the small increase by new consumer the THD is exceeding the permissive level of 2% [1].

This consumer will have to rectify the increase of harmonics which may not be caused by own contribution but indirectly caused by change in network configuration.

In years 30 onwards the configuration has changed and with the increase of lines and transformers the fault level increases with the effect of decreasing the THD as well. So next customer that comes will again be in much better situation regardless of how much he contributes to the THD.

4. DISCUSSION

This period, when the same amount of load connection in years 20 and 25 use the available margin in disproportion, seems to be unfair to the customer that is last to connect and picks up the bill for all previous consumers.

The customer in year 20 is using 10% of the installed capacity but ¾ of the available THD headroom while the customer in year 25 is also using 10% of the installed capacity but by his 5% harmonic contribution he is causing the increase above the THD limit and is liable to pay for it. It would be therefore reasonable to consider more even share of usage of the overall margin specified for voltage level at Point of Common Coupling. This could be achieved by coordination of the transmission and distribution Operators, who are responsible to maintain the adequate level of power quality in terms of harmonics as well as voltage variation, reliability etc.

Similar issues with providing the reactive power into the system in order to maintain the required voltage limits should also be considered and options to equally share provision of the reactive power into the system by generation companies and transmission and distribution system operators [2].

5. CONCLUSIONS

The presented cases illustrate that major consumers and customers when connecting to the power systems may use the full available margin between their contribution in harmonic distortion and stipulated limits. Only the THD has been shown in the paper, although this applies for each individual harmonic.

It is shown that once the THD limit has been reached the next consumer to connect is obliged to mitigate the distortion even if his contribution towards harmonic pollution is negligible. For this reason this issue is brought up and further consideration of transmission and distribution operators and major consumers is recommended. It would be reasonable to assume that the transmission and distribution operators would take the leading role in organising a more share distribution of investment by all consumers and users.

If this is to be accepted one of the benefits to the

transmission and distribution operators would be better network planning and management from the power quality aspect which would likely be acceptable from the regulatory point of view.
The main activities associated with this process would be modelling and measurements. Modelling of the network would include network elements and type and characteristics of the load. Important part would also be scanning for resonances of each harmonic order. Network development should be checked with the Seven Year development plan to monitor the load increase and short circuit level.
Measurements would be required for model validation and confirmation of the harmonic prediction for various scenarios.

REFERENCES

[1] Engineering Recommendation G 4/5

[2] V. Polimac, M. Pezic; 2003, "Identified voltage control options within the T&D network service providers in contests of reactive power Market in Spain", CIRED 17th International Conference on Electricity Distribution Barcelona, 12-15 May 2003

FURTHER WORK

It is recommended that this issue of even distribution of harmonic mitigation among the consumers is more explored for example by listing it as one of the topics for the next conference.
It would also be beneficial to invite major customers such as major transportation companies to share their view and prepare a paper or create a forum where all views including the regulators would be heard.