ONE OPTIMISED NETWORK EQUIPMENT

Using source information in harmonic assessments

Introduction

Harmonic assessments of renewable generation projects involve the key steps of identifying the frequency dependent impedance of the network upstream of the point of connection, modelling the various operating modes of the generator network including all cables and transformers, and applying the harmonic emissions from the various power electronic sources in the generator, whether solar, wind, or battery based.

The significant uncertainty and variability relating to upstream network conditions are normally dealt with by modelling the network as a set of resistance and reactance ranges that define polygons for each harmonic order of interest and that captures the complex impedance that the network may exhibit under all considered conditions.

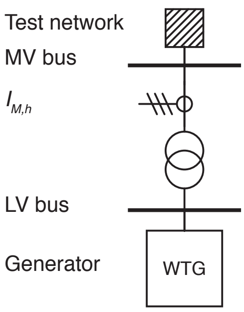
Reviewing the several combinations of generator configurations that may occur, taking into account various levels of generation, connection of collector groups, and uncertainty relating to the relevant cable and transformer parameters ensures generator operating modes are robustly considered.

The treatment of harmonic emissions from power electronic sources has traditionally been to use measurements taken according to the requirements of the IEC 61400-21 (2008) standard, that defines how power quality parameters of wind turbines should be quantified. Modelling these harmonic sources then simply means applying the measured current as an ideal current source. Without information on the internal characteristics of the inverter and associated components used to connect the inverter to the collector system, this is the only correct approach to modelling the harmonic source.

There are clear and important problems with this approach that can influence the harmonic assessment and associated harmonic filter design significantly in terms of cost, ratings and performance.

Measurement of current emissions

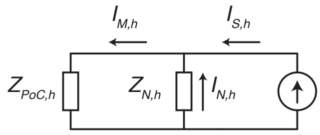
The above mentioned standard requires current harmonic measurement under a set number of operating conditions, normally in a test configuration as shown below.



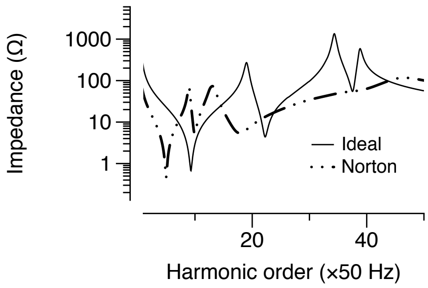
The measured current $I_{M,h}$ is used as an ideal current source in models when no other information is available on how source current is influenced by the network to which it is connected.

Norton impedance

The reality is that the current source is not ideal. The current at the terminals of the generator is influenced by internal features of the inverter (related to passive filter equipment at the inverter terminals as well as characteristics of inverter stacks themselves) as well as the network impedance. Modelling systems attempt to represent this by means of the Norton equivalent impedance of the harmonic source as represented below.



This is an important change to the model. The figure below, taken from a typical wind farm, illustrates the impact on impedance at a node in the wind farm when treating harmonic sources as ideal current source and when taking the Norton equivalent impedance into account.



There are orders of magnitude difference in impedance across a range of harmonic orders. This difference will clearly make a marked difference to the outcome of harmonic assessments and any associated filter designs. It is therefore of critical importance to the developer of the wind, solar or battery generator to make the Norton equivalent impedance information available for the most appropriate modelling due to the obvious cost, performance and time implications.

Determining the Norton equivalent impedance is not a trivial exercise and is not limited to just the passive filter circuit commonly connected to the input stages of inverters to mitigate emission of specific frequencies related to inverter switching. The power electronics itself exhibit distinctive frequency and load dependent impedance. Early indications are that time domain modelling of inverters may be able to provide this information. Much work is still required to calibrate the calculated impedance against results obtained from measurements under controlled conditions.

Source current

Information on the Norton impedance $Z_{N,h}$ above is clearly of key importance in the harmonic emission assessment process. Associated with this is the source current $I_{S,h}$ in the above diagram. This current is clearly not the same as the current $I_{M,h}$ and should be provided by the generator manufacturer together with the Norton impedance. It is certainly not correct to apply the measured current as if it is in fact the source current.

If the generator manufacturer does not provide the source current information, it is possible to estimate the current if the test conditions to determine $I_{M,h}$ are known, from

$$I_{S,h} = I_{M,h} \left(1 - \frac{Z_{N,h}}{Z_{PoC,h}} \right)$$

assuming that for the test configuration the impedance of the network was known within acceptable margins of error as a function of frequency.

It is unusual to find details of the test configuration in the IEC 61400-21 test reports. This is a major shortcoming of the standard (alongside the lack of requirement to record any prevailing background harmonic distortion, and the fact that the background harmonic distortion is only required to be less than 5% V_{THD}).

When no information is available on the test configuration at all, but information on the Norton equivalent impedance is provided by the generator supplier, together with the measured current $I_{M,h}$, then it may be of some use to assume that the network impedance is linear and based on a certain multiple of the generator rating. This arbitrary assumption of network impedance may yield more appropriate source current information than simply modelling the generator as an ideal current source with no internal impedance.

Impact on filter design

In the face of a high level of uncertainty regarding the internal impedance and actual source current of non-linear generators, designing harmonic filters that can be guaranteed to mitigate harmonic distortion to within compliance levels is an onerous task. One major driver in the filter design is the over-arching requirement to avoid aggravating existing, or establishing new harmonic resonances within combination of generator and upstream networks.

This is generally achieved by means of harmonic filters that are tuned to low frequencies, and application of damping circuits that ensure harmonic distortion is absorbed across a wide range of frequencies. Optimisation of such designs is made difficult given that it is known beforehand that harmonic source information is not quantified well.

Conclusion

The arguments made here can be summarised as follows: harmonic assessments should be based on the most accurate information available. Robust approaches to network impedance and generator system impedance result in low risk in the assessment relating to these aspects. Modelling of harmonic current sources as non-ideal may have a very significant impact on the outcome of a harmonic assessment and harmonic filter design. The cost, performance and even viability of a project may depend on whether an accurate model of the generator is available.

Filters can be designed to ensure compensation for this lack of information but optimisation of designs is difficult.

Accurate and proven information on the Norton equivalent impedance as well as the associated internal harmonic source current is essential to guarantee reliable harmonic assessments and filter designs.