NAME : Jason David
COUNTRY: Australia
REGISTRATION NUMBER: 5695

GROUP REF.: C4
PREF. SUBJECT: 1
QUESTION N°: 6

Power quality mitigation is becoming increasingly complex, particularly for networks with high penetration of Inverter Based Resources (IBR). In particular, interactions of harmonic emissions between IBR dominated plants is capable of leading to inefficient mitigation solutions being considered. Such complications are demonstrable in cases in which harmonic remediation, such as passive harmonic filters are designed to operate at the PCC of a plant but do not have sufficient information regarding the harmonic impedance of nearby plants (existing and future).

In countries such as Australia, Brazil and the UK (among others), it is the responsibility of the customer to implement appropriate mitigation measures to ensure the harmonic emissions of the proposed or existing plant do not exceed their allocated emission limits. In order to design and apply the proposed mitigation, a representation of the network is necessary that includes the effects of existing (and committed) customers in the area.

Passive components, such as reticulation network cable, power transformers and reactive plants (e.g. capacitor banks and harmonic filters), connected in close geographical (and electrical) proximity, results in the components having a large impact on the network harmonic impedance. These impacts subsequently affect the appropriate design of harmonic mitigation for connecting customers. Added difficulties exist in these circumstances due to restricted access to information or knowledge of such components being connected within another plant.

An exploratory study has been undertaken in which the efficiency and efficacy of plant-based harmonic mitigation (i.e. mitigation connected within the plant) is compared with network-led solutions, i.e. harmonic mitigation applied throughout a network to address non-compliant harmonic voltage levels. The study considered a radial network, shown in Figure 1, with long feeders and the connection of numerous IBR plants along each feeder. The electrical representation of the network was based on industry provided data, for an area that is expected to connect substantial amounts of renewable energy in the next 20 years. An IEC TR 61000.3.6:2012 allocation approach, following the process in Appendix B of the technical report, was implemented to ascertain appropriate emission levels for each installation. A single harmonic order (12th) was investigated to compare the necessary filtering based on a simplified pre-connection compliance assessment. Note that the most efficient approach to harmonic mitigation is likely to be a broadband style filter that may vary significantly between different filter designers. This study instead determines the necessary filter rating for a single (notch) filter to ensure the proposed plant remains compliant. This approach allows a direct comparison of a plant-based solution against a network solution with minimised effects of varying filter design techniques. Further, the design of each filter is executed without the knowledge of other plants and their filter, to replicate common conditions.

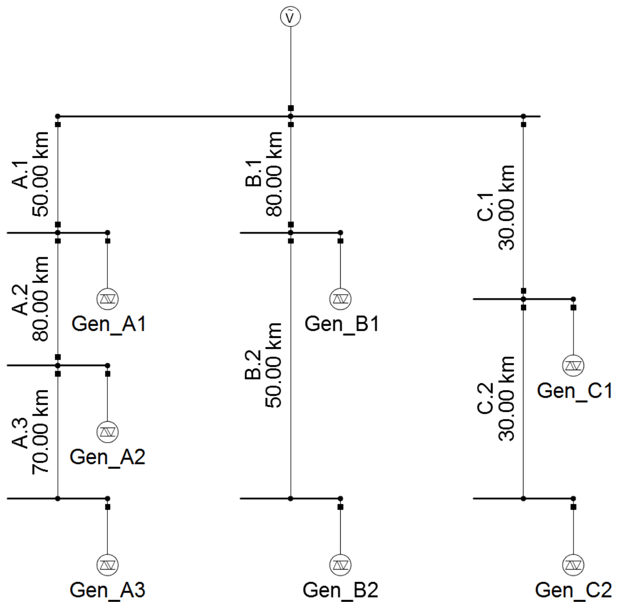

Figure 1 - Radial network used for study

Harmonic distortion at each bus without any mitigation connected was calculated including the network planning levels, the results are shown in Figure 2.

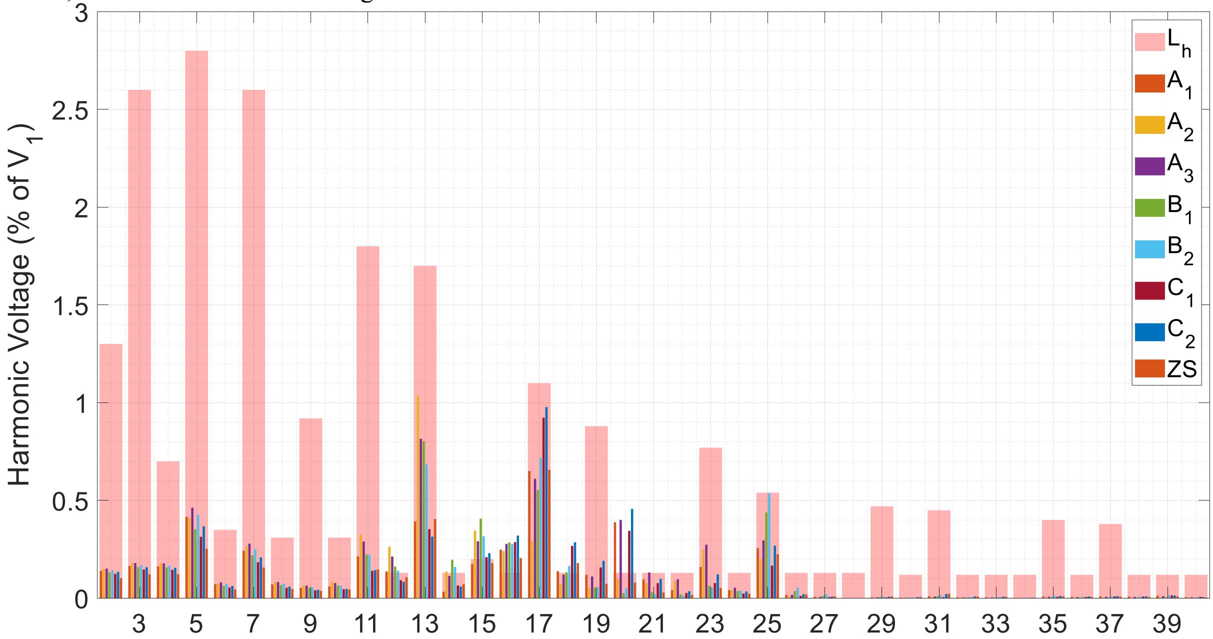

Figure 2 - Harmonic voltage without filtering connected

A simplified pre-connection compliance assessment determined that all installations were determined to be non-compliant with their allocated emission limits. As previously mentioned, mitigation for a single harmonic order only was considered to allow for a focussed comparison of mitigation solutions. The required filter rating, when being connected at the PCC of each installation, is provided in Table 1. These values are the necessary filter sizes for each installation to meet their allocated emission limits for a single harmonic order.

Table 1 - Required filter rating for plant-based mitigation

Plant	Q_{filter} $(kVAr)$
A.1	190
A.2	70
A.3	280
B.1	40
B.2	120
C.1	32.5
C.2	27.5
$\sum$	**760**

A harmonic emissions calculation was then executed. The resulting harmonic voltages at each bus including system planning levels is shown in Figure 3. Showing that whilst the harmonic emissions of the 12th order are considerably lower and remain compliant across the network, the impact this has on the remaining harmonic orders is substantial, notable, a significant amplification occurs at the 15^{th} harmonic order.

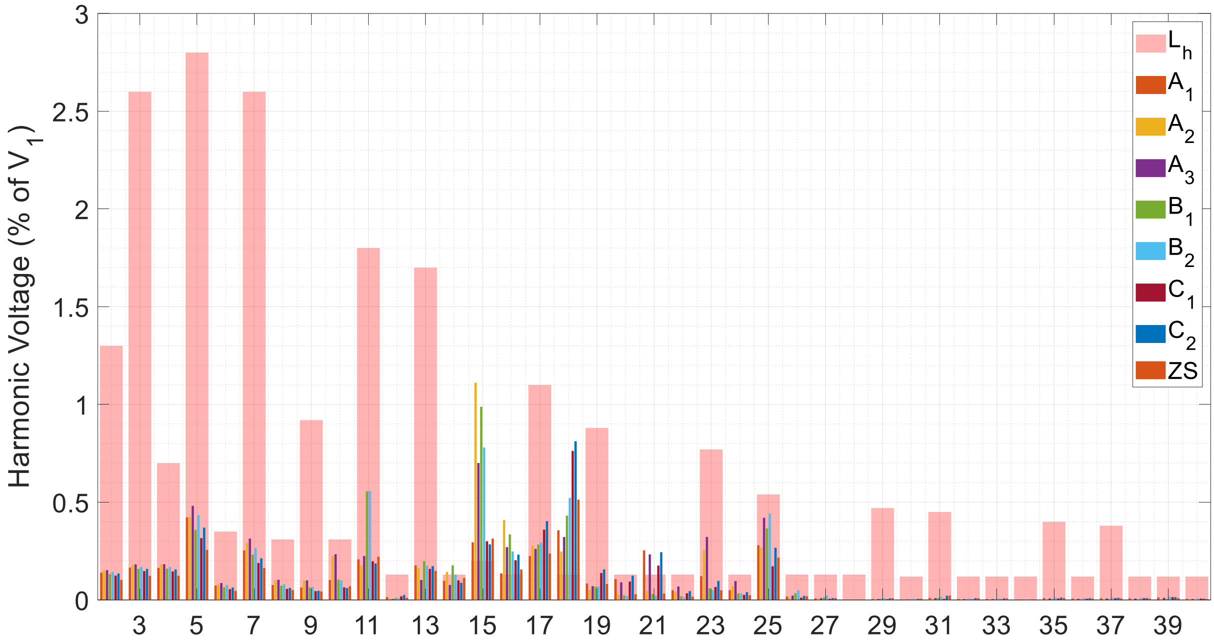

Figure 3 – Harmonic voltage levels with all filters connected at the PCC of non-compliant installations

It must be noted that these impacts will be more pronounced in this study given the consistent use of notch filters, however, the use of broadband filters would require an increased MVAr rating and is capable of having further and/or more widespread interactions between individual plants.

A network-led approach was then considered in which a notch filter was connected to the network at the point at which the maximum harmonic voltage occurred without any filters connected (i.e. busbar A.2, as per Figure 2). The required filter size was 20 kVAr, suggesting a 97 % reduction in total filter size being required to ensure network planning levels are maintained. Further, a comparison of the resulting harmonic distortion levels considering the two approaches of mitigation for a representative busbar is shown in Figure 4.

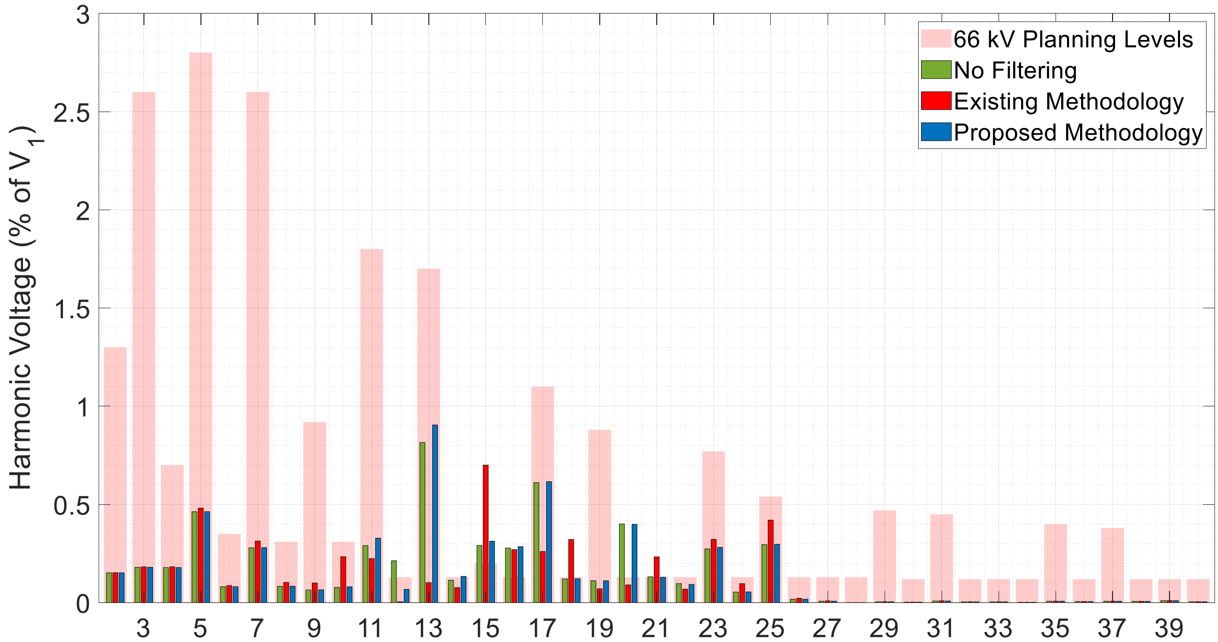

Figure 4 - Comparison of harmonic voltage distortion values

The results show that a network-led approach to harmonic mitigation not only reduces the required sizing of the filters but also reduces the potential impact on surrounding harmonic frequencies. Considering the mechanism of the outcomes discussed from this study, one may consider the impacts of PQ mitigation and suggest that, in general, interactions between IBR plants are capable of occurring remote to the individual plants. Network-led solutions are thus expected to be capable of providing more robust, efficient approaches to mitigate such impacts and should be considered particularly in networks with high penetration of IBR.