Study Committee C4

Power System Technical Performance

Paper ID: 11038

Harmonic Filters Characteristics Effects in the Switching Manoeuvre Transient

Juan CHACÓN*[1], Dominique ALONSO SORENSEN[1], Manuel DE LA HOZ[2], Cristina RIOJA BARÓN[1]

ARTECHE SMART GRID[1], UNIVERSITY OF THE BASQUE COUNTRY UPV/EHU[2]

Motivation

The ongoing integration of Renewable Energy Sources (RES) with power electronics interfaces, has led to an increase of reactive power compensation and harmonic filtering to improve grid´s power quality.

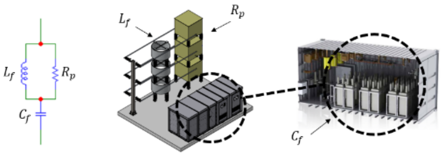
Reactive power compensation and harmonic filtering manoeuvring is completely attached to the different operation modes of the RES power plant. Hence, they are frequently connected and disconnected.

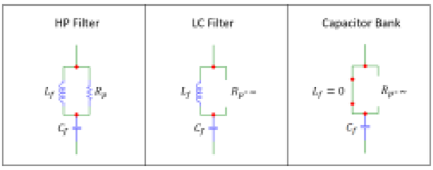
The phenomena is well studied for capacitor banks, but for harmonics filters only the case of first order filter, with no resistive elements is found.

This research aims to analyse the impact of the filters' design parameters and external grid's parameters, on the transients generated by a harmonic filter connection.

Harmonics Filters Types

For the connection study a High Pass (HP) filter is chosen because first order filters (LC) and capacitor banks can be considered a simplified case of this type of filter.





A LC filter can be derived from the HP filter by disconnecting the parallel resistance (Rp = ∞), so that the LC is a particular case of the HP filter. Similarly to the previous case, a capacitor bank can be derived from the LC filter by considering an inductance with null reactance (lf = 0).

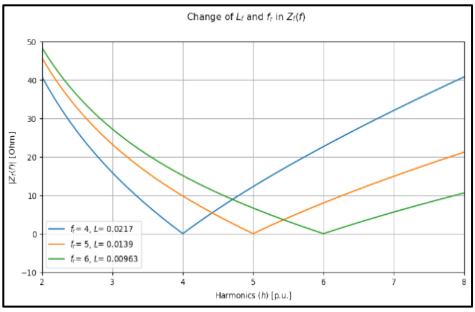
Filter Parameters

The HP filter can be completely defined by three key parameters [10]:

- Tuning frequency, fr :

$$f_r = \frac{1}{2\pi\sqrt{L_f \cdot C_f}} \quad (1)$$

$$h_r = \frac{f_r}{f_n} \quad (2)$$



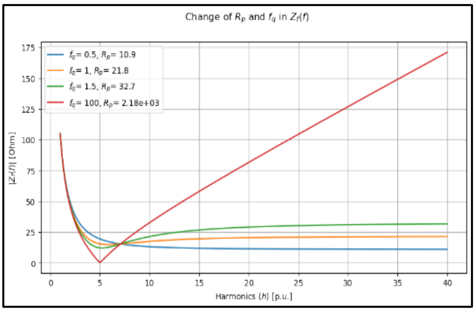
- Reactive power (at fundamental frequency), Qf :

$$Q_{cb} = \omega_n \cdot C_f \cdot U_n^2 \quad (3)$$

$$Q_f = \frac{Q_{cb}}{\left(1 - \frac{1}{h_r^2}\right)} \quad (4)$$

- Quality factor, fq :

$$f_q @ f_r = \frac{R_p}{X_L @ f_r} = \frac{R_p}{2 \cdot \pi \cdot f_r \cdot L_f} \quad (5)$$



Study Committee C4

Power System Technical Performance

Paper ID: 11038

Harmonic Filters Characteristics Effects in the Switching Manoeuvre Transient

External Grid

Analysed from the filter bus, the entire upstream power system can be modelled considering a Thevenin equivalent as follows:

- short-circuit power of the network at the filter connection point (S_{cc}).
- ratio of inductance versus Thevenin's impedance resistance of the equivalent network (X/R).

Network parameters have been set by categorizing them as "strong" or "weak" according to their strength regarding the filter burden and according to their inductivity, as a typical characteristic that differentiates transmission network (Tx) from distribution (Dx) networks.

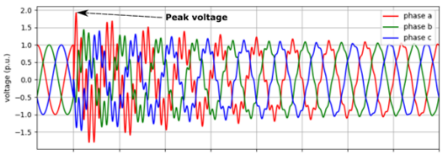
Network strength
Strong Net (S_{CC}/Q_f = 100)
Weak Network (S_{CC}/Q_f = 20)

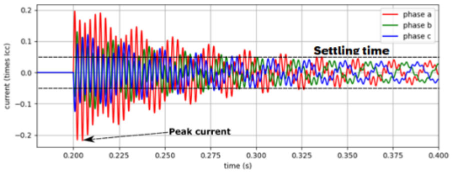
Network "Inductiveness"
Distribution - Dx (X/R = 3)
Transmission - Tx (X/R = 10)

Key Performance Indicators (KPI)

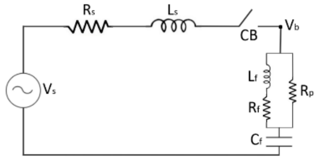
Three main indicators will be used to analyse the influence of the filter parameters on the generated transient:

- The maximum or peak voltage observed at the connection point, regardless the phase.
- The maximum or peak current, also phase independent.
- The settling time of the transient phenomenon, considering the end of the event at the exact moment when the current in the filter is within a band of 2% of its final value.





Model Description



Although the model is represented by the individual components, the study is carried out in terms of the grid's (X/R ratio and Scc) and the filter´s (Qf, fr, and fq) parameters.

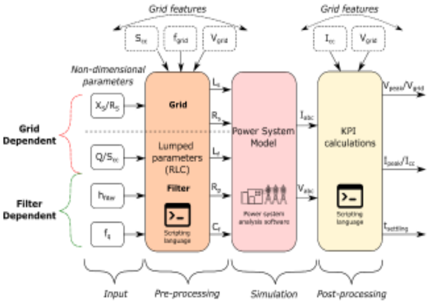
Description	Non-dimensional parameter
Relative **grid** inductance	X_S/R_S
Relative **grid** strength	S_{CC}/Q_f
Harmonic filter resonance frequency	h_f
Harmonic filter quality factor	f_q

Methodology

EMT (Electro Magnetical Transient) studies have been performed for the closing operation of a harmonic filter's CB (Circuit Breaker).

The filter is switched-on when the voltage phase "a" is maximum, which corresponds to the worst scenario for capacitor banks connection.

As can be observed on the figure, for each study case (set of parameters XS/RS, SCC/Qf, hf, and fq), complete EMT simulations are performed, KPIs are calculated, and results are stored.

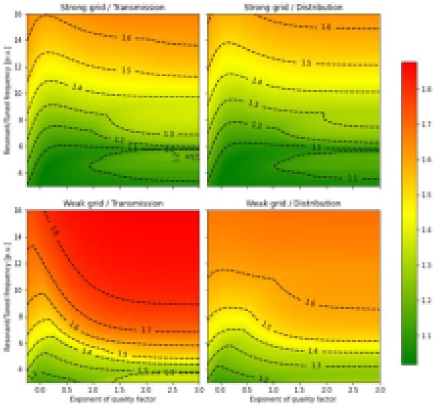


- The overvoltage (V_{peak}/V_{grid}) is expressed in p.u. considering as the base value the nominal voltage of the network the filter is connected to (V_{grid})
- The inrush current (I_{peak}/I_{cc}) is expressed also in p.u. considering the short-circuit current of the network as the base value (I_{cc})

Study Committee C4
Power System Technical Performance
Paper ID: 11038

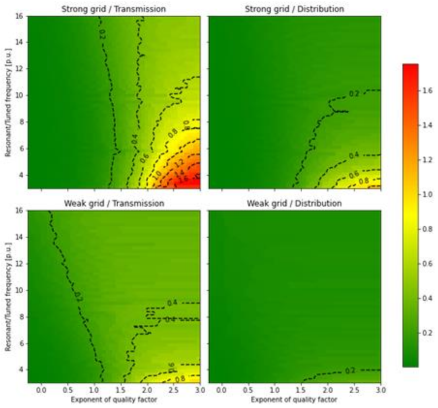
Harmonic Filters Characteristics Effects in the Switching Manoeuvre Transient

Maximum Voltage (V_{peak}/V_{grid})



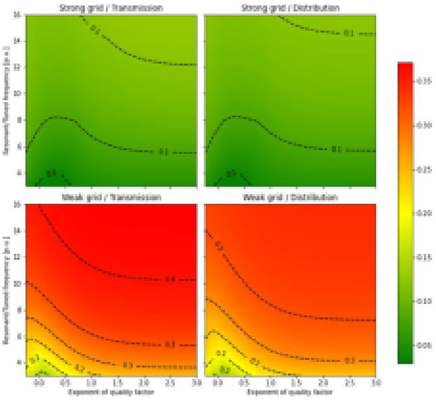
- The most severe overvoltage occur in “weak” grids in relation to the filter size.
- Filters with higher tuning frequency are more likely to generate overvoltage problems.
- Filter quality factor has an influence on the overvoltage generated by the filter´s switching.

Settling Time



The settling time could become a problem in a strong (inductive) transmission network where low-frequency filters with poor damping factor are connected.

Maximum Current (I_{peak}/I_{cc})



The inrush current depends mainly on the short-circuit power of the network, not because a strong network can supply a higher current; but because in a weak network, the filter switching transient can reach a considerable magnitude relative to the short-circuit current (30%).

Conclusions

Considering the results obtained, it can be established that the transitory behaviour of the filter connection not only depends on its constructive aspects but also on the strength and inductivity of the network it is connected to.

Based on the results presented in this article, it can be concluded that the maximum overvoltage values (≈1.8 p.u.) reached for a harmonic filter switching did not exceed the maximum obtained in a capacitor bank manoeuvring (2p.u.); although the values can be very similar depending on the application. Due to this aspect, it is recommended to develop a complete specific model and study for the identified critical applications. Future research in this topic should consider aspects as back-to-back connection and other elements of the grid.

All conclusions are based on the premise that the closing operation is carried out at the maximum voltage of one of the phases, which is the worst switching case for capacitors banks. As future work it should be consider extending the analysis by adding the switching instant as an input variable.