Reactive power compensation in electrical networks

Information from Merus Power

Modern electrical installations supply power to a wide variety of non-linear loads, where the current drawn does not have a linear relationship with the voltage supplied. This results in distortions in the current and voltage waveforms. The degree of distortion in these waveforms tends to increase according to the number of non-linear loads in a facility.

Since non-linear loads always produce harmonics when connected to an AC voltage supply, it is impossible to eliminate them completely. They can be limited to some degree by using harmonic filters. An active harmonic filter (AHF) monitors the harmonic currents and injects a current of equal but opposite magnitude to cancel them out.

The principle of active harmonic filter operation

Active filters measure all three phases of line current in real time and generate the measured harmonic currents and/or fundamental reactive current in the opposite phase by means of a combination of a digital signal processor (DSP) and field programmable gate array (FPGA) semiconductor devices.

The AHF provides a real-time stepless compensation for any reactive current waveform.

The main components in an AHF system are capacitors used for energy storage, high frequency semiconductor switches and inductors for the system connection. The voltage level of the energy storage is controlled to be continuously higher than the peak value of the supply system voltage.

This principle enables current flow, controlled by high frequency semiconductors, from energy storage to the supply system. The device can be understood as a controlled current source which provides any kind of reactive current waveform in real time.

This kind of current source can be overloaded by double output current for short periods within semiconductor thermal limits. Therefore, active filters can provide output power at 1,1 and 0,9 pu system voltage as follows:

$$Q_{AF} = 1{,}1 * 2 * I_{AF} = 220\%$$
$$Q_{AF} = 0{,}9 * 2 * I_{AF} = 180\% \qquad (1)$$

Merus A-series active harmonic filter operation modes

Active filters can be set to operate in the mode that offers the best power quality result for each application.

All harmonics operation mode

This operation mode offers real-time compensation of all harmonics and fundamental reactive power. Fundamental frequency active and reactive load can be balanced in this mode. The response time of the active filter in this mode is less than 100 µs.

All harmonics but no fundamental frequency operation mode

Frequency load balancing and reactive power compensation is excluded in this mode. The response time of the active filter in this mode is less than 100 µs.

Selectable operation mode

This operation mode offers the possibility of selecting the harmonic order to be compensated. Percentage of compensation degree for orders 1 – 25 can be set (0 to100%) to each order individually. Odd and even harmonics can be selected. The response time of the active filter in this mode is equal to fundamental frequency cycle time.

Merus A-series active harmonic filter harmonic current mitigation performance

Merus active filters can to filter simultaneously from the second to the

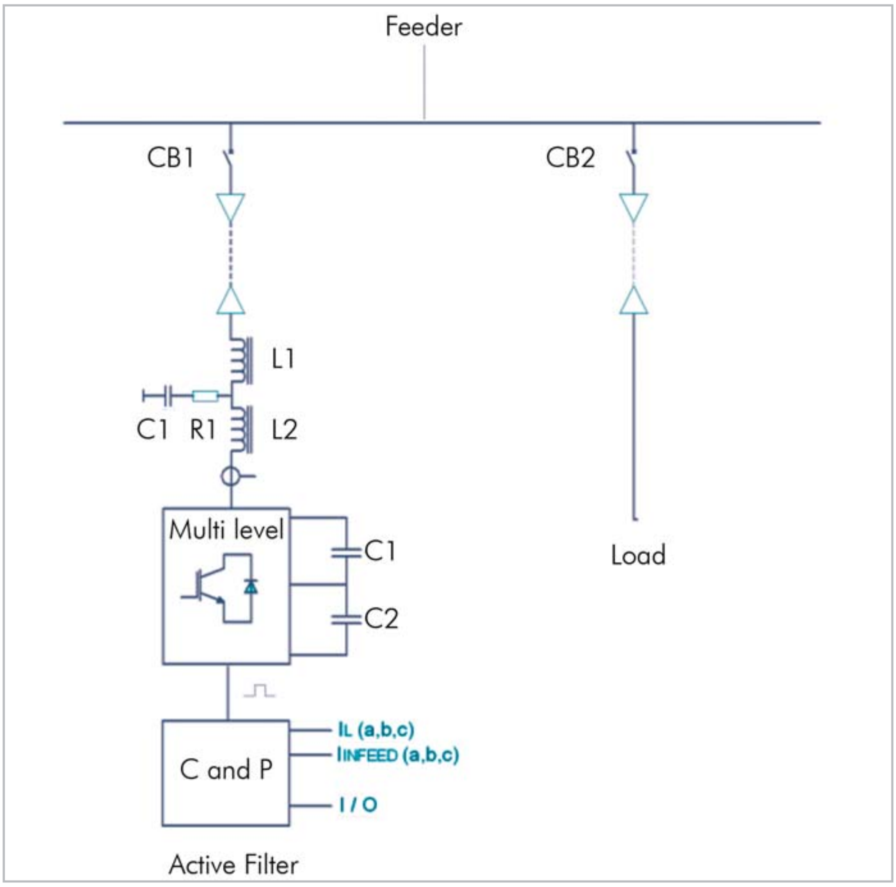

Fig. 1: Typical active harmonic configuration for industrial applications.

50th harmonic including even harmonics and inter-harmonics. The active filter can provide fundamental frequency reactive power compensation. Target power factor is selectable in capacitive or inductive mode.

Filtering and reactive power compensation efficiency of 95% or better is possible, provided sufficient filter capacity is available. Merus active filters cannot be overloaded due to harmonic currents, making them safe to use in systems where harmonic current generation keeps changing and increasing.

Thyristor switched capacitors (TSC) operation principle

Thyristor switched capacitors (TSC) are used for reactive power compensation of relatively fast-changing symmetrical three-phase loads. TSCs can be understood as a step-controlled impedance which provides reactive power that is proportional to the square of the system voltage.

The impedance provides output power which is proportional to the system voltage. Therefore, the exact output of each step is not defined by the TSC type compensator itself, but is defined by the system voltage as follows:

$$Q_{SVC} = \frac{1{,}1^2}{Z_{SVC}} = 121\%$$
$$Q_{SVC} = \frac{0{,}9^2}{Z_{SVC}} = 81\% \qquad (2)$$

The limitation of a conventional contactor-controlled power factor scheme is the DC charge of the capacitor unit after disconnection from the supply system. The DC charge time is delayed since the polarity of DC charge and the polarity of the supply voltage is not known at the time of connection. More than double the voltage could be applied to capacitor unit which may be fatal.

The conventional contactor from normal power factor correction systems has been replaced by a thyristor switch, including switching logic, in order to shorter the compensation system's reactive power response delay.

Thyristor technology gives the advantage of switching the capacitor unit into service regardless of the charge of the capacitor unit. The voltage across the thyristor switch is monitored to determine an optimal switching time.

When the capacitor unit is discharged the switching moment is zero-crossing of the voltage causing, to some extent, a switching transient. The ideal transient-free switching moment occurs when the instantaneous voltage of a charged capacitor unit and the system voltage are equal.

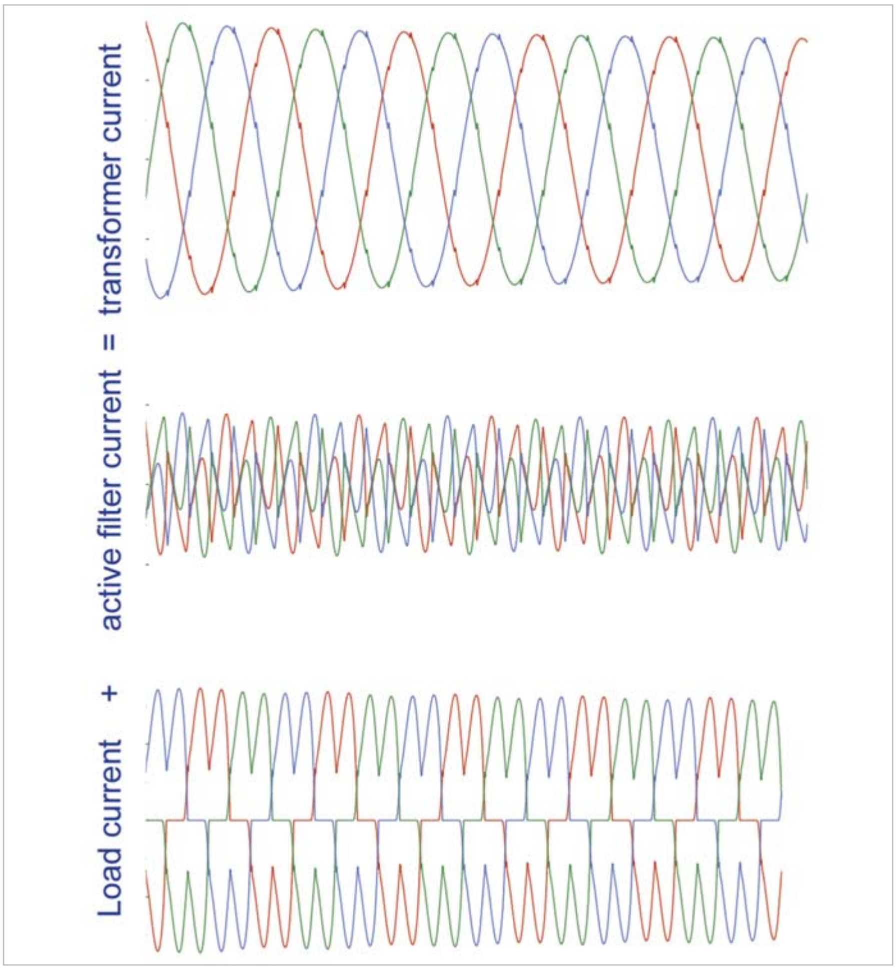

Fig. 2: Waveforms when all harmonics and fundamental reactive power is compensated.

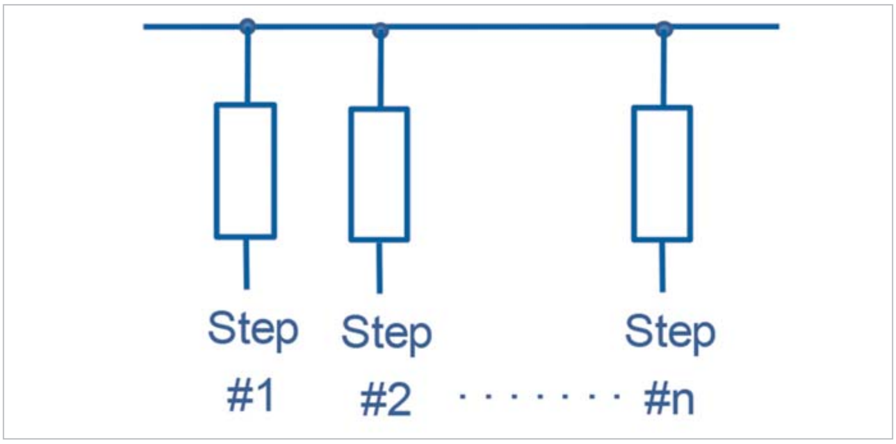

Fig. 3: TSC can be simplified as step controlled impedance.

Since series reactors are used for tuning the resonance frequency of the capacitor bank, the remaining DC voltage at the capacitor unit is higher than the system voltage. Due the nature of system behaviour some voltage difference between DC charge and system voltage has to be tolerated, which leads to moderate switching transients.

Thyristor switched capacitors (TSC) response time

The amplitude of the switching transient and the switching response time must be compromised according to the application in which the TSC used. The minimum theoretical switching response time of the capacitor step is one cycle, but in reality it is two to three cycles (40 to 60 ms).

TSC reactive power compensation accuracy

The TSC compensates fundamental reactive power by the accuracy of the selected capacitors step size. The nominal output power of each step is based on nominal voltage, while in reality the output is proportional to the actual system voltage being applied.

TSC harmonic current performance

The thyristor has a limited ability to withstand currents with higher frequencies than fundamental. This limitation results from the finite speed of the recovery process after turning off. This leads to a limited ability to withstand several current zero crossings during the fundamental period. If the current waveform is distorted and contains extensive harmonic currents, several zero crossings exist which poses a risk of thyristor failure due to forward recovery. A rule of thumb is that the amount of harmonic currents through a TSC switch should never exceed 50% of the total RMS current.

To avoid excessive amounts of harmonic currents, TSC banks are often equipped with 7% reactors leading to 189 Hz tuning frequency of passive filtering. Therefore, the harmonic filtering ability is limited and dependent upon the system impedance vs. TSC impedance at harmonic frequency. A general rule of thumb is that 300 kvar TSC can reduce harmonic current distortion by 25%, thus 75% harmonics are still flowing into the feeder system.

Merus A-series active harmonic filter operation and voltage distortion

Merus active filters can be regarded as current sources which generate a controlled output current waveform depending only on the load harmonics and selected filtering settings.

Thus, the effect of voltage distortion on filtering performance is negligible.

Merus A-series filters have been especially designed to prevent excessive voltage distortions jeopardising the reliability of capacitor banks and passive filters.

Some active filter products have been known to suffer from component failure due to voltage distortion and/or commutation notches caused by DC drives.

The ripple filter design is especially critical in this case. Merus A-series filters are robust and have been proven to work reliably even in the presence of commutation notches and high voltage distortion of more than 15% (UTHD). Should conditions worsen beyond

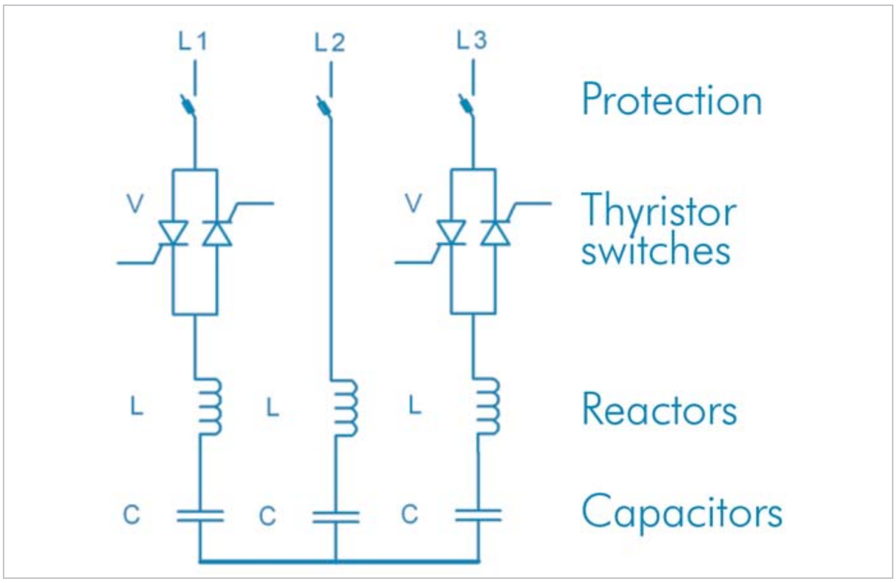

Fig. 4: Thyristor switched capacitor bank.

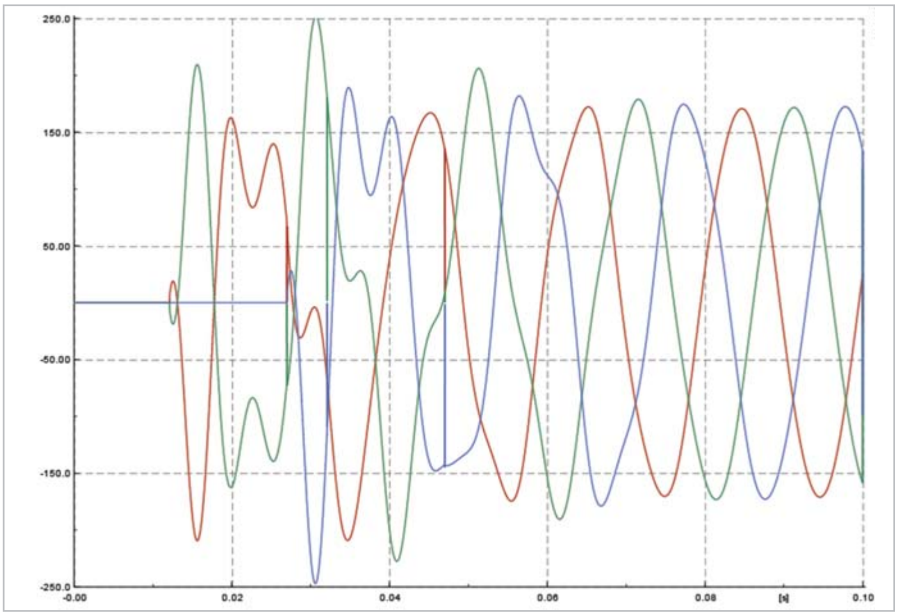

Fig. 5: Discharged capacitor inrush current.

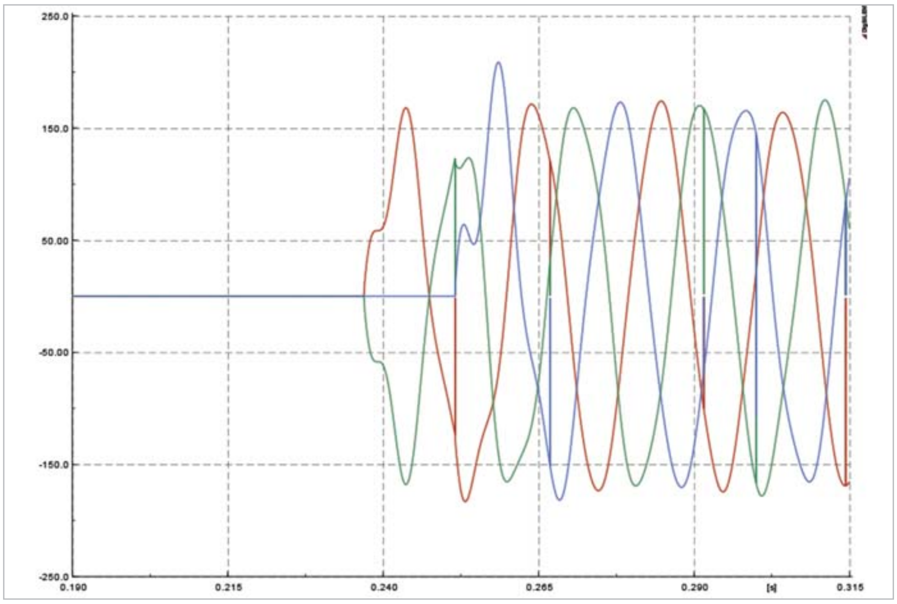

Fig. 6: Charged capacitor inrush current.

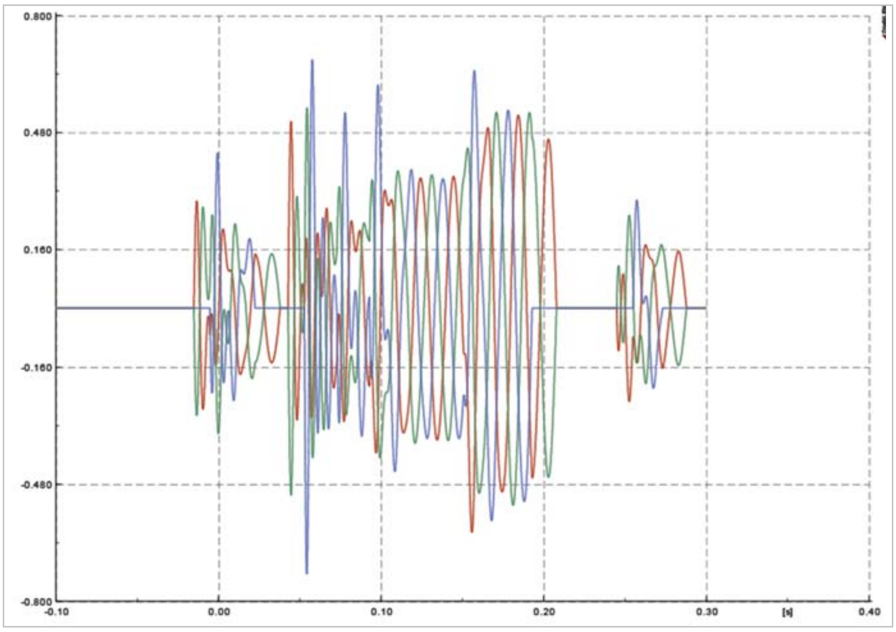

Fig. 7: TSC compensation current steps.

the allowed limits for any reason, the integrated protections operate before any damage occurs. This guarantees reliable operation in all conditions.

TSC and voltage distortion

TSC switches that try to minimise switching transients synchronise the switch-on time moment with the supply voltage, taking the DC charge of the capacitors into account.

If the supply voltage has high distortion, it is likely that – with presence of high voltage distortion – the switch-on moment determined by the TSC switch electronics gets disturbed which leads to excessive switching transients. Depending on the overall design, this may lead to premature failure of capacitors, TSC switches and/or other components in the system, and may cause further distortion to the supply.

One of the most problematic conditions from this point of view arises from DC drives which cause commutation notches on the voltage. High voltage distortion also causes harmonic currents flowing into the TSC as it acts as a passive filter.

High voltage distortion, caused by adjacent or upstream systems, may cause high distortion in the TSC current. This may lead to an overloading of the entire TSC step which may be impossible to prepare for in the design stage.

In general, for reliable operation of TSC banks the voltage distortion should be less than 8% (UTHD). If the distortion is worse than this, it is advisable to decrease the voltage distortion by means of active filtering.

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