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Impact of Multi-Cycle Symmetrical Control on Power System

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***Summary*: Multi-Cycle symmetrical control (MCSC) for application above 1.2 kW fails compliance tests once IEC 61000-4-7 [1] edition 2 introduced a new assessment method which groups inter-harmonic into the harmonic levels. MCSC-driven apparatus up to 3 kW may succeed the compliance test if IEC 61000-4-7 neglects interharmonic components at frequencies below the second harmonic order. Upon the power level, MCSC-driven apparatus could disturb the ripple-control system needed for communication. Probabilities of disturbance at 116, 183 and 216 Hz with MCSC applications above 1.2 kW exceed the 5% EMC rule particularly for power rating nears to 3 kW.**

Key words:
power quality, harmonic, flicker, MCSC complance test IEC standards

1. INTRODUCTION

The multi-cycle symmetrical control (MCSC) turns on and off the same amount of positive and negative half-cycle currents in specific sequences to reduce the power without losing the symmetry of the current waveform.

Multi-cycle patterns combined with full-wave or off-wave intervals allow linear power-level adjustment of heater elements upon the MCSC to full- or to off-wave ratio (Fig. 1). Such system performs very well for fine tuning the power delivered to heating elements found in some heating apparatus, water heaters and cooking plates.

Load switching causes fluctuation of the mains voltage that in turn produces light flicker. MCSC patterns alone can supply up to 3 kW without producing unacceptable flicker level. However, the flicker level momentarily increases when MCSC period abruptly changes to full or off cycles. Therefore, the global flicker rises as the rate of transitions increases. For very accurate heating control, MCSC applications should use about one transition per second (60/min) but such sequence at that rate cannot connect heaters above 2.4 kW because of visible flicker. To increase the heating element to 2.8 kW without producing flicker, MCSC sequence should reduce transitions at about 8 per min.

The second solution to reduce flicker consists to avoid abrupt changes in the power during each transition. The dimmer circuit with monotonic firing angle provides smoothed transition. As shown in figure 2 and 3, several schemes can perform the smoothed transition. For optimal power adjustment without excessive flicker, the sequence should take 3-s duration with two 0.5-s smoothed transitions.

With this approach the Pst remains below 0.95 although the controlled power reaches 3 kW.

In addition to flicker problem, MCSC circuit with a dimmer produces interharmonic and harmonic signals. According our tests, a sequence of 6-s duration with transitions in the range 110- to 250-ms intervals becomes the preferred sequence to avoid both distortion and flicker above the compliance limits.

For assessing harmonic current emission level of equipment, IEC 61000-4-7 standard [1] requests to group interharmonic signals with the harmonic component. Because of the grouping, the second order of class-A harmonic current [3] (h_2) may be exceeded by MCSC-driven apparatus in the power rating above 1.2 kW.

Since 1987, Germany widely installed MCSC-driven apparatus with rated power up to 2.5 kW without problem observed. Therefore the IEC national committee in Germany requested to modify the grouping function to avoid compliance test failure of 2.5-kW MCSC-driven apparatus. As solution, IEC SC77A/WG1

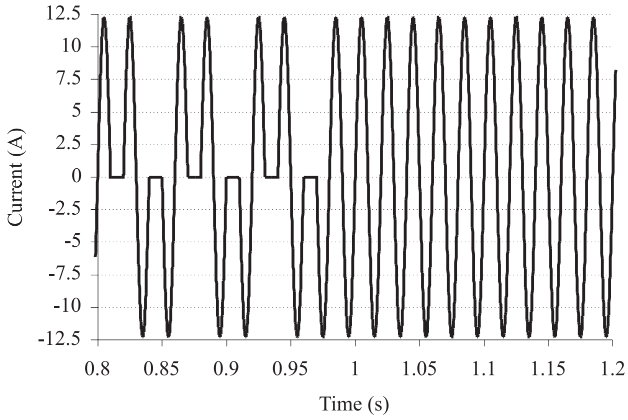
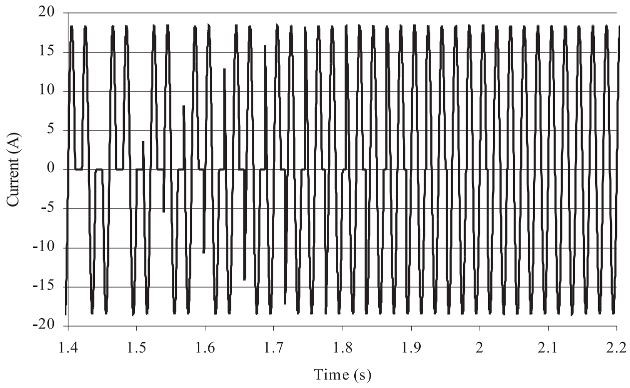


Fig. 1. Example MCSC current scheme

a)



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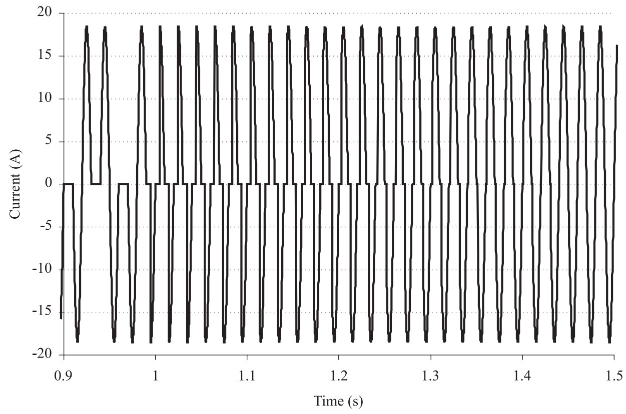


Fig. 2. Smoothed MCSC to full wave transition using dimmer; a) smoothed transition included in MCSC waveform; b) smoothed transition included in the full wave

proposed starting the grouping function at the second harmonic value e.g. to ignore the inter-harmonics in the 75-100 Hz range (90-120 Hz for 60 Hz systems).

This report addresses the impact of MCSC application on the ripple-control system used for communication purposes.

2. METHODOLOGY

For the purpose of this study, special software was designed to perform the following tasks:

For the current:

— Generate digital waveform currents $I(t)$ at 10240 sample rate (2048 samples per 0,2-s window) for MCSC sequences presented in figure 1 to 3.

— Perform FFT on each 0.2-s window.

— Group each harmonic and interharmonics according IEC 61000-4-7.

— Perform the 1.5-s smoothing of grouped harmonic according IEC 61000-4-7.

— Repeat the sequence to obtain the results of 3000 windows (50 min) of grouped and smoothed harmonic assessments.

— Average these results over 50-min interval for each grouped and smoothed harmonic order.

— Compare these averaged values with compliance limits of IEC 61000-3-2.

For the voltage:

— Generate digital waveform current of several apparatus assuming random starting time and random MCSC patterns (Fig. 3)

— Approximate the voltage waveform $U(t)$ by the following equation when 1 or 2 apparatus are connected to a network characterized by $R + jX\,\Omega$ impedance.

$$U(t) = V(t) - RI(t) - \left(\frac{X}{2\times\pi\times 50} \times \frac{I(t) - I(t-\Delta t)}{\Delta t} \right)$$

where:

— $V(t) = 230\times\sqrt{2}\,sin(2\pi 50t)$ approximately in phase with $I(t)$

— $R = 0.4$ and $X = 0.25$ for flicker analysis

— Assess the Pst level using the algorithm described in IEC 61000-4-15.

— Perform the DFT on 9-cycle windows of the voltage disturbed by of two MCSC using random patterns and starting time.

— Compare voltage components with the admissible levels found in IEC 61000-2-2.

3. HARMONIC EMISSION CURRENT

Providing the grouping equation in IEC 61000-4-7 starts at the second harmonic order, MCSC circuit can supply up to 2.5-kW heater elements without failing the harmonic compliance test. The smoothing technique in 6-s sequence with 500-ms full-wave interval can extend the controlled power to 3-kW and maintain harmonic emission below the class-A limit [2] (see Fig 4).

4. VOLTAGE INTERFERENCE

It just takes one 3-kW MCSC-driven apparatus to disturb ripple-control system operating at 116 Hz at most location. When two independent 3-kW units operate at the same location, disturbance of MCSC-driven apparatus may cancel each other but may also add together. If perfectly synchronized, two 3-kW MCSC-driven apparatus produce significant voltage distortion (Fig. 5) at location where the network impedance is higher than or equal to 0.4 + 0.25j Ω.

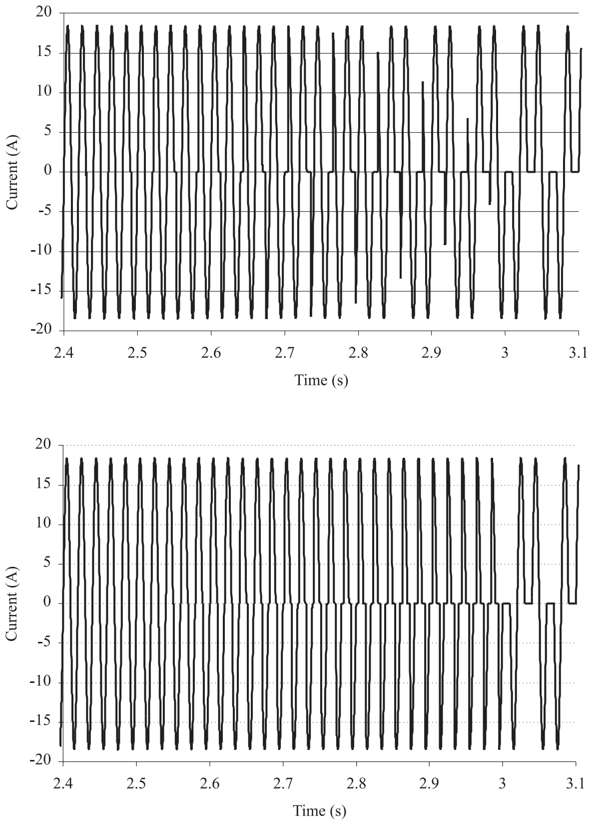
When considering more than one MCSC application, at least three independent stochastic variables play a role in the probability to disturb ripple-control systems. First, each apparatus may not start at the same time. Since each MCSC pattern comprises 3 half cycles, the second apparatus may start at one of these 3 possible half cycles resulting to 3 possible values for this stochastic variable. Second, three possible patterns may compose the signal produced by MCSC applications. One of these patterns supplies the apparatus during two half cycles and turns off the power during the following half cycle (Fig. 1). In opposition to this previous pattern, the MCSC connects the apparatus during one half cycle followed by two half cycles at "off" position. Finally, all half cycles could remain at "on" position. This variable represents several independent stochastic variables e.g. one for each MCSC-driven apparatus. The probability assessment consisted to generate 100 simulations with values of starting time and MCSC patterns obtained randomly.

In relation to the network impedance and the stochastic process explained above, the probability assessments reported in table 1 use 0.2% voltage-distortion limit in accordance with the reference level suggested in IEC61000-2-2 [3]. These results give the probability associated to two 3-kW MCSC-driven apparatus disturbing the ripple-control system. These probabilities should increase when considering possible resonance of power-factor capacitors particularly at frequency around 200 Hz or when more than two 3-kW MCSC-driven apparatus connects on the same power line.

To be disturbed by MCSC-driven apparatus, the ripple-control system should also be sensitive at specific frequencies such as 116, 183 and 216 Hz. For example, MCSC-driven apparatus operated in Germany since 1987 revealed no problems because only 2.5% of the ripple-control systems operate at frequency generated by MCSC applications. Because of very few ripple-control systems operate at these critical frequencies, the global probability to be disturbed is much below 5% in Germany.

5. CONCLUSION

Germany installed many 2.5-kW MCSC-driven apparatus without observing problems mostly because very few ripple-control systems in that country operate at frequency generated by these apparatus. Replying to German national committee, IEC SC77A/WG1 suggested modifying the equation 8 of IEC61000-4-7 standard to start the grouping at the second harmonic order. This modification aims to achieve harmonic compliance test with MCSC-driven apparatus above 1.2 kW. When using smoothed transition technique, the proposed modification can tolerate MCSC-driven apparatus up to 3 kW without failing both harmonic and flicker compliance test as described in IEC 61000-3-2 and in IEC 61000-3-3 standards.



a)

b)

Fig. 3. Smoothed full wave to MCSC transition; a) Smoothed transition included in MCSC waveform; b) Smoothed transition included in the full wave

Although MSCS-driven apparatus did not produce observable problem in Germany, these apparatus generate 116, 183 and 216 Hz components reserved for ripple-control communication systems. As the power of MCSC application increases or power-system resonance phenomenon occurs, the probability to disturb the ripple-control system at 116, 183 and 216 Hz also increases. Provided that several MCSC-driven apparatus of power rating above 1.2 kW connect together on the same power line, ripple-control systems operating at 116, 183 or 216 Hz may be disturbed with a probability above the 5% EMC rule [3] unless these systems operate at other frequencies. This

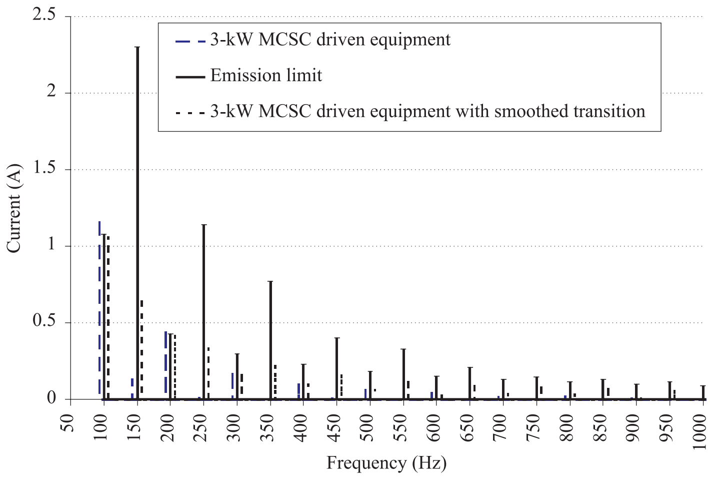


Fig. 4. Current harmonic emission

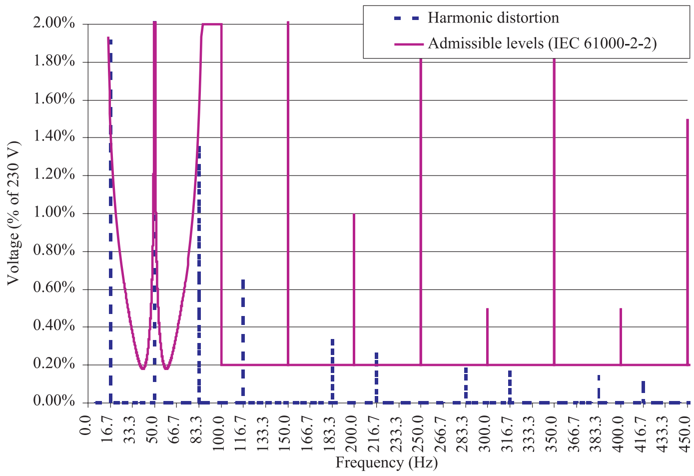


Fig. 5. Example of voltage distortion produce by two perfectly synchronized 3-kW MCSC-driven apparatus connected at location where network impedance is 0.4 + 0.25j Ω

Table 1: Disturbance probability by two 3-kW MCSC-driven apparatus upon network impedance.

→ Frequency ↓ Probability	116.7 Hz	183.3 Hz	216,7 Hz
8%	0.12+0.07j Ω	0.24+0.15j Ω	0.30+.19j Ω
31%	0.14+0.08j Ω	0.27+0.16j Ω	0.34+.21j Ω
87%	0.24+0.15j Ω	0.47+0.29j Ω	0.57+.36j Ω

report gives an example of two 3-kW MCSC-driven apparatus operated at the same location that disturb ripple-control system with a probability above 5%.

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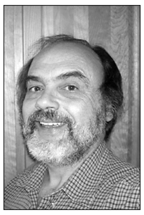

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