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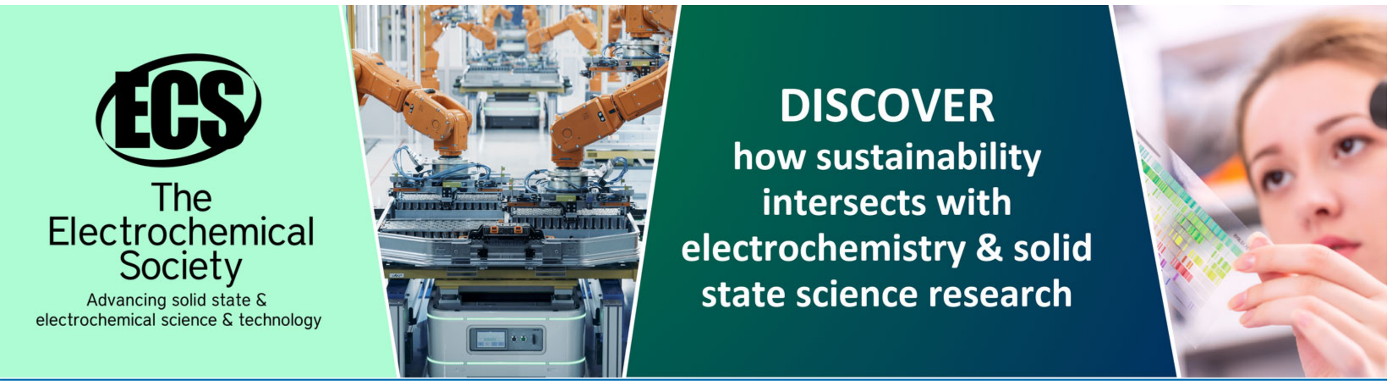

Higher harmonics and limiting thereof in power supply systems of different voltages

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Abstract. The simulation of the modes of power supply systems of different voltages, with a transformer carrying linear and non-linear loads and a capacitor bank, has been implemented. The dependences of the capacitors overload by current and the coefficient of harmonic voltage components on the capacitor bank capacity within the operating range of the transformer total load by linear and non-linear loads have been obtained. For the systems under consideration, upon a daily variation in the capacitor bank linear load and capacity, it is virtually impossible to eliminate the capacitors overload by higher harmonic currents and observe regulatory voltage quality requirements. Anti-resonant chokes installation in the capacitor bank circuits reduces the overload of capacitors to a permissible value, and brings up the coefficient of harmonic voltage components to values that took place in the absence of the capacitor bank.

1. Introduction

Semiconductor converters, widely used in industrial and town mains [1, 2], change current and voltage waveform of the mains and create an electromagnetic compatibility challenge in terms of generating higher current harmonics due to the strong nonlinearity of volt-ampere characteristics of semiconductor valves. Current harmonics, spreading over the mains, degrade voltage quality and negatively affect all electrical equipment of the power supply system (PSS), and, in particular, cosine capacitor banks (CB), causing overload thereof by current [3-5].

Many scientific papers, devoted to the study of higher harmonics in the PSS, contain the analysis of harmonic currents spread, as a rule, in a simplified single-phase model, wherein each higher harmonic is deemed to be a source of current with infinite capacity, i.e., a constant value [1, 6, 7]. The works, devoted to the matters of the generation, variation in value depending on reactive power compensation ratio and spread of higher current harmonics in three-phase models of the PSS of different voltages with a semiconductor converter as a direct source of these harmonics, are missing.

2. The aim of the research

The aim of the research is to study higher harmonics in three-phase PSS of different voltages with non-linear load and to assess the efficiency of applying anti-resonant chokes to reduce the negative effect of harmonics on the equipment of these systems and voltage quality.

3. Models of power supply systems

The PSS, with a power source – a transformer, carrying linear and non-linear loads and a capacitor bank to compensate for linear load reactive power, is considered. A three-phase bridge rectifier was analysed as non-linear load.

Both computer and physical simulations of the PSS non-sinusoidal modes were used during the research. Computer simulation was carried out using the *Multisim* industrial standard and the *MATLAB* software. Transformers of conventional power with the voltage of 10/0.4 kV and 110/10 kV were considered as power sources: for the voltage of 10/0.4 kV – 250, ... 2500 kVA; for the voltage of 110/10 kV – 6300, ... 63000 kVA.

The basic assumption, accepted during the computer simulation, was the following: all active inductive elements of the PSS were accounted for by inductance and active resistance, calculated for the fundamental harmonic.

Physical simulation was carried out using a laboratory model with a dry-type transformer with voltage of 0.4/0.23 kV and capacity of 19 kVA, applying a three-phase bridge rectifier VS-26MT60 with diodes, designed for the repetitive voltage of 600 V and an average current of 25 A. Wire rheostats and chokes were used as the rectifier load and the transformer linear load, and the assembled CB was adjusted stepwise within the range of 10 ... 320 μF.

For summing up the simulation results, all the controlled capacities were presented in relative units relative to the transformer rated capacity: capacity on the side of non-linear load $P^*_d = P_d / S_{t\,nom}$; linear load capacity $S^* = S / S_{t\,nom}$; capacitors output $Q^*_{CB} = Q_{CB} / S_{t\,nom}$.

Studies, using a laboratory physical model, were carried out at $P^*_d = 0.25$ and $S^* = 0.2$.

4. Simulation results

As is known, the most negative impact by higher harmonics is observed under resonant modes between the transformer inductance and the CB capacitance. Upon a daily variation in linear load and, accordingly, the CB capacity, the resonant mode can be obtained at any stage of the controlled CB [8]. Therefore, for the PSS uder consideration, the dependences of the CB overload by current (K_{OVL}) and the total coefficient of harmonic voltage components (K_U) on capacity Q_{CB}^* within the operating range (up to 70%) of the transformer total load by linear and non-linear loads are presented below.

Figure 1 illustrates the results of computer simulation of the PSS modes with a 10/0.4 kV transformer, having capacity of 1000 kVA. Hereinafter, the permissible values for the K_{OVL} and K_U coefficients are shown with dashed lines. It can be seen that the permissible modes virtually occur only between the resonances at the 7th ($Q_{CB}^* \approx 0.37$) and 11th ($Q_{CB}^* \approx 0.15$) harmonics. For transformers of other capacity within the considered range of 250 ... 2500 kVA, no qualitative differences were observed, and some quantitative differences were due to the increase in the short-circuit voltage $u_к$ increasing with the transformer capacity from 4.5 to 6.0%.

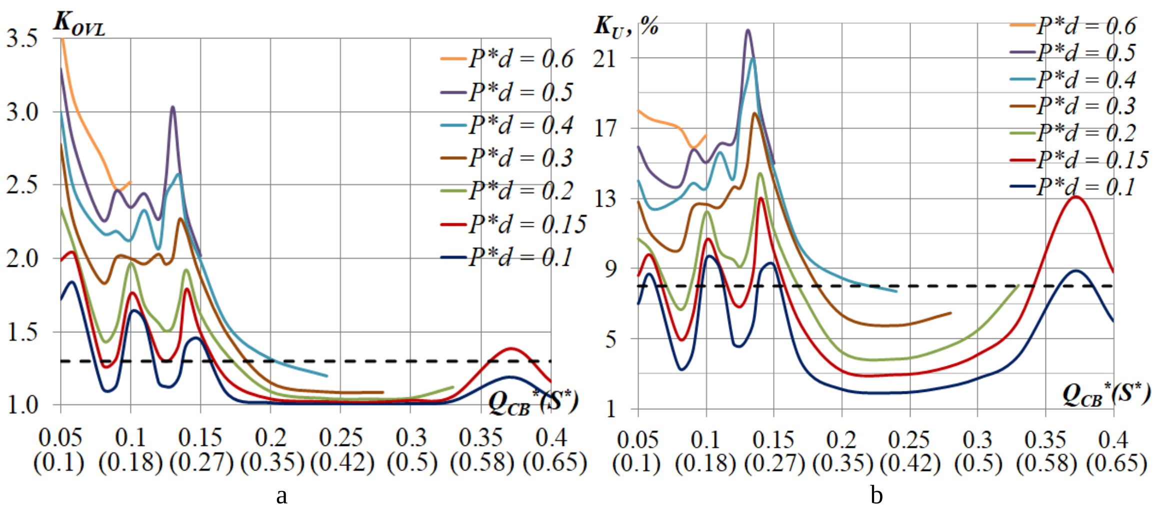

Figure 1. Dependencies of the K_{OVL} (a) and K_U (b) coefficients on the transformer load in 10/0.4 kV PSS

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110/10 kV transformers of different rated capacity have the same values of $u_к$ = 10.5%. As a result of the simulation, it was stated that in such PSS the values of the K_{OVL} and K_U coefficients did not qualitatively differ, and some quantitative difference is due to different designs of the transformer (without or with the secondary winding splitting).

Figure 2 illustrates the simulation results of the PSS modes with a 110/10 kV transformer, having capacity of 6300 ... 16000 kVA (without the secondary winding splitting). It can be seen that permissible modes also occur between resonances at the 7th ($Q_{CB}^* \approx 0.18$) and 11th ($Q_{CB}^* \approx 0.07$) harmonics, but only for the values of $P^*_d \leq 0.2$ by the CB current load and for $P^*_d \leq 0.1$ by voltage quality.

Figure 3 presents similar physical simulation results. It is seen that at $Q_{CB}^* < 0.17$, the CB current overload by higher harmonics is inadmissible. In addition, within the entire range of variation in capacity Q_{CB}^*, the quality of voltage is unsatisfactory.

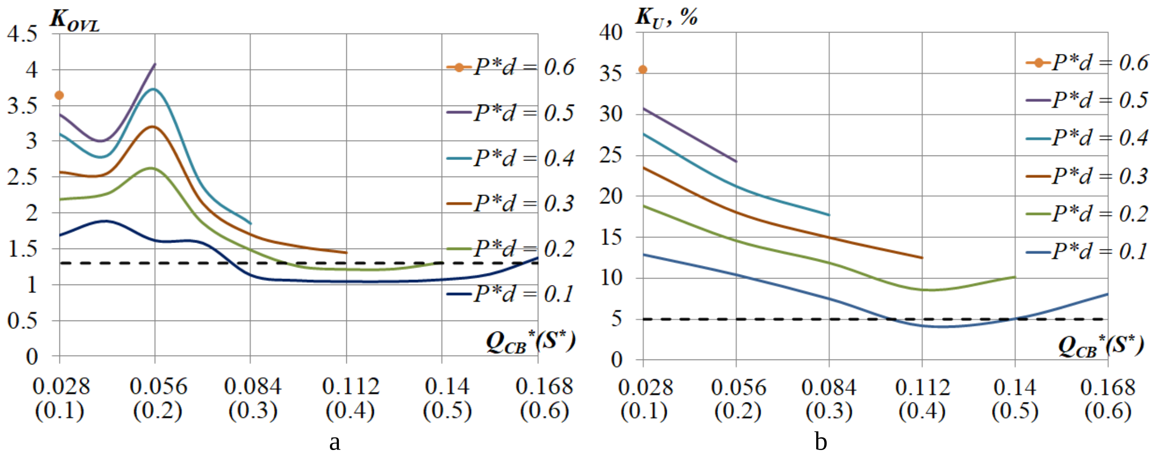


Figure 2. Dependencies of the K_{OVL} (a) and K_U (b) coefficients on the transformer load in 110/10 kV PSS

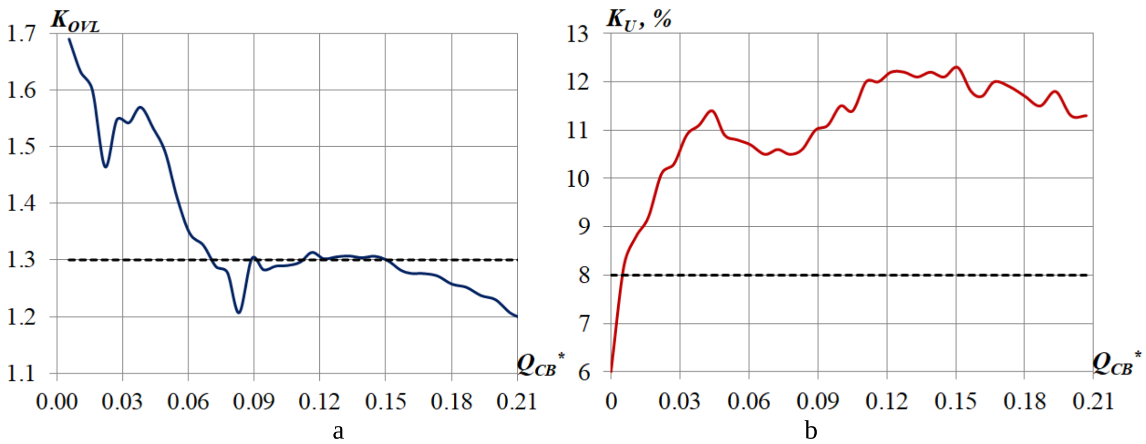
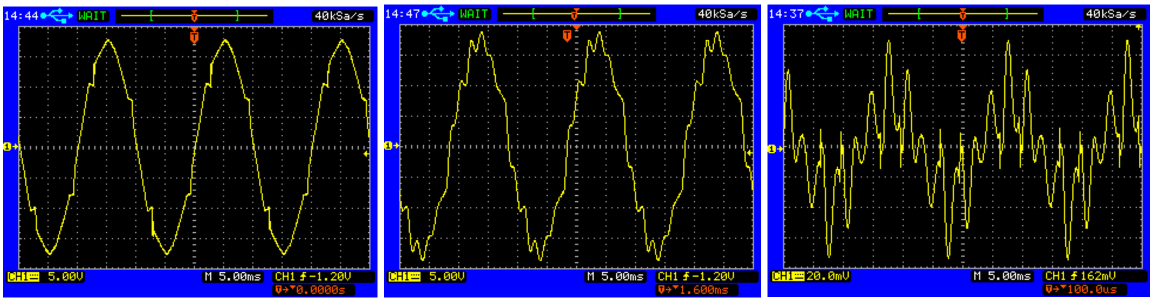


Figure 3. Dependencies of the K_{OVL} (a) and K_U (b) coefficients on the transformer load according to the PSS physical model

It is worth noting that the CB installation in the presence of non-linear load degrades voltage quality [9]. Thus, in 10/0.4 kV PSS at $Q_{CB}^* = 0$, voltage quality requirements are met under capacity of $P^*_d \leq 0.7$, and in 110/10 kV PSS – under capacty of $P^*_d \leq 0.2$ and $P^*_d \leq 0.1$, respectively, for transformers without and with the secondary winding splitting. The aforesaid is confirmed by physical simulation (Figure 4, a, b). At $Q_{CB}^* = 0$, the voltage curve contains characteristic step-like distortions, corresponding to current switching intervals by the rectifier valves (Figure 4 a, and K_U = 6%). When the CB is installed, an oscillating term with the frequency of the characteristic harmonic, closest to the frequency of the circuit “the transformer inductance – the CB capacitance”, occurs in voltage (Figure 4, b and K_U = 11%). The closer these frequencies, the greater the oscillating term amplitude and, accordingly, the worse the quality of voltage (the greater the K_U coefficient).



a b c

Figure 4. Physical model: oscilloscope traces of voltage at Q_{CB}^* = 0 (a) and at Q_{CB}^* = 0.055 (b) and oscilloscope trace of current in the CB at Q_{CB}^* = 0.13 (c)

The CB current overload by higher harmonics in the mode, close to the resonant one, is illustrated by oscilloscope trace 4, c, wherein the resonant 7th current harmonic with an amplitude, comparable to the amplitude of the first (fundamental) harmonic, is clearly observed.

5. Suppression of higher harmonics

Known methods to suppress higher harmonics are circuit designs for rational arrangement of the PSS with non-linear load, as well as the use of dedicated companion devices: active harmonic filters (AHF); filtering compensation devices (FCD); anti-resonant chokes (reactors) [10-12].

In terms of financial viability, the latter method is more cost efficient than the use of FCD and AHF [13]. The essence of this method resides in varying the amplitude-frequency curve of the network relative to the capacitor bank in order to eliminate resonant phenomena. Reactors can be installed in different units of the PSS [13]. However, by the capacity value, the most advantageous is to install anti-resonant chokes (reactors) in the CB circuit, which was accounted for further simulation implementation.

The standard choke resistances, adopted by the VDEW (Association of German Power Supply Companies), in fractions of the CB resistance at a frequency of 50 Hz make 14% and 7%. The first option is used to protect capacitors against all harmonics, starting with the 3rd one, the second option serves for protecting capacitors against all harmonics, starting with the 5th one. Since the harmonics multiple of three was missing in the PSS under consideration, the second option was chosen for further simulation implementation (7%).

The simulation of the 10/0.4 kV PSS non-sinusoidal modes, using anti-resonant chokes, confirmed that within the entire aforesaid range of variation in the transformer load and capacity Q_{CB}^*, the CB load by higher harmonic currents falls within acceptable limits. The overload coefficient is $K_{OVL} < 1.1$. In addition, voltage quality requirements have also been met. The K_U coefficient is $K_U < 8\%$ (Figure 5, a). Moreover, these parameters complied with the entire range of transformers’ rated capacities of 250 ... 2500 kVA.

For the 110/10 kV PSS, the CB load by higher harmonic currents also falls within acceptable limits. The overload coefficient is $K_{OVL} < 1.15$ for the entire range of transformers’ rated capacities of 6300 ... 63000 kVA. Within the considered range of variation in the transformer load and capacity Q_{CB}^*, the K_U coefficient reached 15%. Voltage quality requirements were met only up to capacity P^*_d = 0.2 for transformers without the secondary winding splitting (Figure 5, b) and up to capacity P^*_d = 0.1 for transformers with the secondary winding splitting.

Thus, the installation of anti-resonant chokes brings up the K_U coefficient to the values occurring in the absence of the CB.

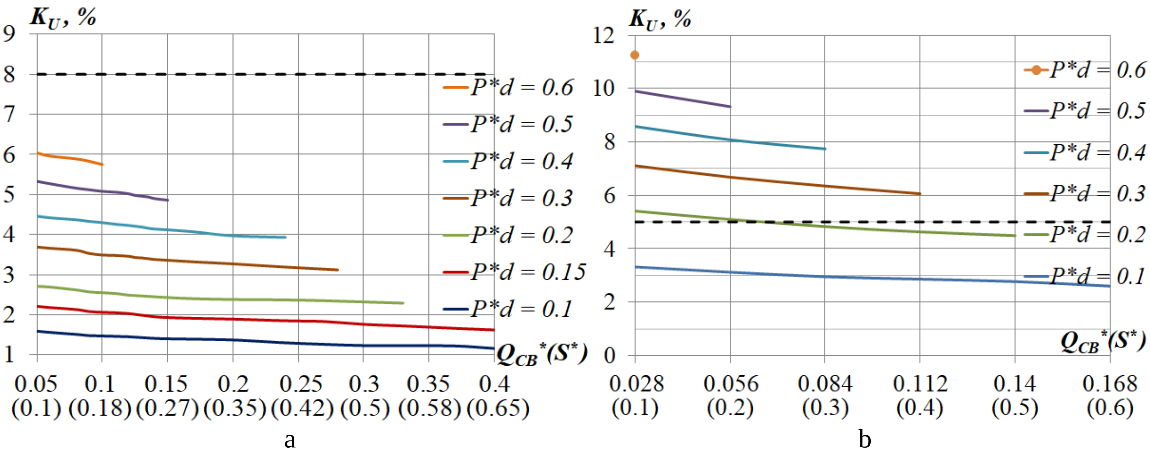


Figure 5. Dependences of the K_U coefficient on the transformer load when installing anti-resonant chokes in 10/0.4 kV (a) and 110/10 kV (b) PSS

If voltage quality requirements are not observed, the circuit designs for rational arrangement of the PSS with non-linear load should be additionally applied. This, in particular, resides in an increase in the pulse number of rectifiers or non-linear load power supply by means of separate transformers or separate windings of multi-winding transformers.

6. Conclusion

Based on computer and physical simulation, quantitative data were obtained to assess the negative impact of higher harmonics on equipment and voltage quality in low-voltage (with 10/0.4 kV transformers of different capacity) and high-voltage (with 110/10 kV transformers of different capacity) power supply systems with linear and non-linear loads and a capacitor bank.

It has been stated that for the systems under consideration, with a daily variation in linear load and a corresponding variation in the capacitor bank capacity, it is virtually impossible to eliminate the capacitors overload by higher harmonic currents and observe regulatory voltage quality requirements.

It has been shown that in power supply systems with linear and non-linear loads, the use of capacitor banks to compensate for linear load reactive power significantly degrades the quality of voltage in terms of its harmonic composition.

To suppress higher harmonics in the considered power supply systems, the efficiency of using anti-resonant chokes connected in series to capacitor banks has been considered. It was proved that in the systems under consideration, the capacitors load by higher harmonic currents falls within acceptable limits, and voltage quality is the same as in the absence of a capacitor bank.

References

[1] Shklyarskiy Y E and Skamyin A N 2011 *Journal of Mininig Institute* **189** 121-124
[2] Temerbaev S A, Boyarskaya N P, Dovgun V P and Kolmakov V O 2013 *Journal of Siberian Federal University. Engineering and Technologies* **6** 107-120
[3] Skamyin A N and Belsky A A 2017 *IOP Conference Series: Earth and Environmental Science* **87(3)** 032-043
[4] Abramovich B N, Ustinov D A, Sychev Yu A and Shkljarskiy A Y 2014 *Oil Industry* **8** 110-112
[5] Belsky A A, Dobush V S 2016 *International Journal of Applied Engineering Research* **11(7)** 4995-4998
[6] Skamyin A N 2011 *Journal of Mininig Institute* **189** 107-110
[7] Dobush V S 2015 *Electronic scientific and practical journal. Modern technics and technologies* **45(5)** URL: http://technology.snauka.ru/2015/05/6851
[8] Skamyin A N and Dobush V S 2018 *IOP Conference Series: Earth and Environmental Science*

194(5) 052023
[9] Kostin V N and Serikov V A 2019 *St.Petersburg polytechnic university journal of engineering science and technology*, **25(01)** 19–29
[10] Abramovich B N and Sychev Yu A 2016 *Journal of Mininig Institute* **217** 132-139
[11] Shklyarskiy Y E and Skamyin A N 2016 *Coke and Chemistry* **59(4)** 163–168
[12] Abramovich B N, Sychev Yu A, Kuznetsov P A, Zimin R Yu 2018 *IOP Conference Series: Earth and Environmental Science* **194(5)** 052001
[13] Shklyarskiy Y E and Skamyin A N 2014 *World Applied Sciences Journal* **30(12)** 1767-1771