Quasi-Instantaneous Generation of Reference Signals for Hybrid Compensator Control

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Summary: **Power variation of a customer load can disturb other loads in distribution systems and compensators for such loads are sometimes needed. Voltages and currents in systems with such loads can be asymmetrical, nonperiodic, distorted and even unpredictable. Consequently, reference signals for the compensator control have to be generated in a situation where the power properties of the load are not well specified. Voltages and currents in systems with time-varying loads, although nonperiodic, can be treated as quantities with a disturbed periodicity. These are referred to as semi-periodic quantities. Under such an assumption, the Current Physical Components (CPC) power theory can by used for estimation of the power properties of such loads. In such a case, the CPC power theory provides fundamentals for a quasi-instantaneous generation of reference signals for the compensator control, based both on the frequency- and on the time-domain approach. The paper presents fundamentals of generation of reference signals for unbalanced loads with semi-periodic voltages and currents.**

Key words:
compensator control, CPC, harmonic filters, hybrid compensators, power variation, power theory, non-periodic currents, semi-periodic currents, harmonics

I. INTRODUCTION

There are some loads in electrical distribution systems that by their very nature operate with high power variation. Spot welding devices, industrial robots, pulse generators in military, science or medicine are these kinds of loads and will be referred to as *Fast Varying Loads* (FVL) in this paper. Such loads can affect the voltage at points of common supply, thus affecting other loads. An increase in switching capability of power semiconductors is a factor that contributes to an increase in power and in the number of FVLs. When a load is supplied from power electronic devices, then the load power variation can be accompanied, moreover, by high distortion of the load current. An example of the active power variation of FVL is shown in Figure 1.

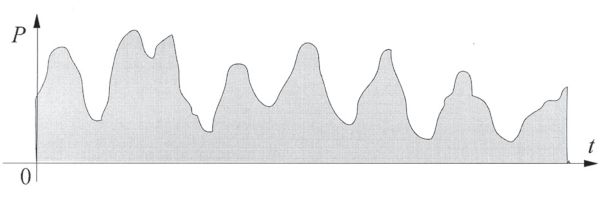

Fig. 1. Example of active power variation of FVL

Fast varying loads affect other loads through the voltage drop on the distribution system impedance, thus their harmful effects are more visible in weak systems then in strong ones. Autonomous isolated power systems, such as naval or oil platforms power systems, can be particularly sensitive to these kinds of loads.

When the level of disturbances caused by FVLs cannot be tolerated, compensators capable of reducing the power variation and waveform distortions are needed.

Reduction of the active power variation is possible only if the compensator has a sufficient energy storage/release capability. High capability of energy storage/release is not needed, however, for reducing current distortion. Capability of high frequency switching for shaping the compensator current is needed instead. Such switching is not needed, however, for compensating the power variation. Thus, compensation of power variation and compensation of current distortion impose opposing requirements upon the compensator. Therefore, building such a compensator as a hybrid compensator (HC), as shown in Figure 2, composed of a *Compensator of Power Variation* (CPV) and a *Compensator of Current Distortion* (CCD) seems to be a viable option.

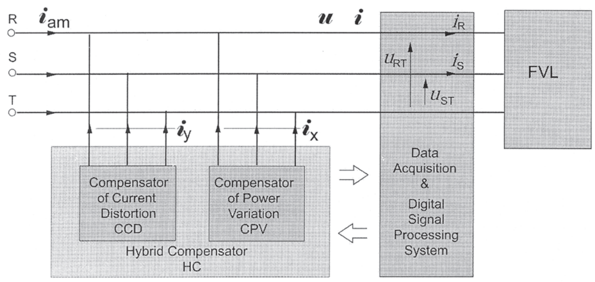

Fig. 2. Structure of a hybrid compensator

Mathematical and physical fundamentals of such compensators operation and control for balanced loads, where a phase-by-phase approach was possible, were presented in paper [1]. This paper extends the approach presented in [1] to unbalanced time-varying loads, where the phase-by-phase approach is not possible. It focuses the attention on the fact that the control algorithm developed in paper [1] provides almost instantaneous generation of reference signals for the compensator control. It demonstrates how this algorithm exploits the frequency- and the time-domain approaches to power theory. The paper was inspired also by a private discussion on the algorithm presented in [1], and in particular, by a question: "*can this algorithm be regarded as a method of instantaneous generation of reference signals for a switching compensator control?*"

Technological means for a hybrid compensator construction, namely, devices for energy storage/releas, based on various physical principles, and Pulse Width Modulated (PWM)-based switching compensators, known as active power filters or power conditioners for reducing current distortion, are now available. There is rich literature on properties and design of such devices. An application of the CPC to their control is presented in [5, 6]. There could be only confusion on how to control such a compensator in a system with FVLs. It is because the compensator control requires that the power properties of the compensated load be identified, while these properties in the case of FVLs are not well comprehended and specified. These properties can be described [2–3] when the load voltages and currents are periodic, but these quantities in systems with time-variant loads are nonperiodic.

The paper shows that in spite of the lack of periodicity, voltages and currents in systems with time-varying loads still have some features that enable the estimation of power properties of such systems and the generation of the reference signals for the hybrid compensator control. The concept of *semi-periodic quantities* [4] will be used for that purpose.

II. SEMI-PERIODIC QUANTITIES

Active, reactive, unbalanced and apparent powers, rms values and the complex rms (crms) values of harmonics in electrical systems are based on the concept of the periodicity, meaning that all quantities repeat with the period T. None of these values can be calculated when the period T is not specified and, of course, nonperiodic quantities do not have any period. Even such a basic quantity such as the active power, P, of a single-phase load with voltage $u(t)$ and current $i(t)$ cannot be specified according to the common definition:

$$P \triangleq \frac{1}{T}\int_0^T u(t)\; i(t)\, dt \tag{1}$$

The same is with other powers, the rms and crms values of harmonics.

Voltages and currents in distribution systems with time-variant loads, although nonperiodic, have some features, however, that distinguish them from other non-periodic quantities. These are:

1. Electric energy to such systems is delivered from power generators at sinusoidal or almost sinusoidal voltages and currents of the period T.
2. Voltages and currents can be regarded as quantities with permanently or transitorily disturbed periodicity.
3. Disturbance of the voltage periodicity is secondary with respect to the disturbance of the current periodicity. It can occur only due to nonperiodic voltage drop on the system impedance.
4. Voltages and currents, due to inductance and capacitance of distribution systems, can change only at a limited rate.

Quantities with these features form a sub-set of the set of non-periodic quantities that can be referred to [4] as a sub-set of *semi-periodic quantities*. Although semi-periodic quantities are nonperiodic, the interval T, equal to the period of the generated voltage, has a particular meaning for semi-periodic quantities. It can be regarded as a main time-frame for power properties of such systems analysis. This interval can be easily detected and will be referred to as an *observation time-window*. Since the voltage is usually much less disturbed than the load current, thus the voltage positive zero crossing can be used for this interval detection. Low pass filters can be used, when needed, to reduce the effect of even-order harmonics and noise for the zero crossing. Such an observation time-window is shown in Figure 3.

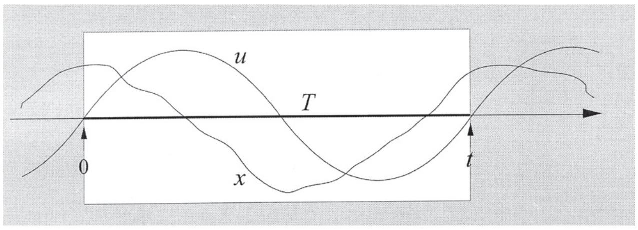

Fig. 3. Observation time-window with semi-periodic quantity x

The assumption that the power properties of the load at the instant of time t are approximated based on the obser-vation of voltages and currents of the load in the interval of time $t - T$ preceding the instant t is the main assumption for the method discussed. Thus, the observation window runs with the moment of observation. It is called a *running observation window*. In particular, the common definition of the active power (1) should be superseded with

$$\tilde{P} \triangleq \frac{1}{T}\int_{t-T}^{t} u(t)\; i(t) \tag{2}$$

It can be calculated not earlier, but at the instant t, meaning, at the end of the running observation window. Therefore, it is referred to as a *running active power*.

III. REFERENCE SIGNALS FOR CPV AND CCD

The active power in systems with FVLs can be regarded, of course, only in the sense of definition (2) and this power could be a fast varying quantity. Compensation of this power variation means that compensator reduces the deviation of the running active power from its median value, calculated over an averaging interval $T_a >> T$. This median active power at instant t is:

$$\tilde{P}_m \triangleq \frac{1}{T_a}\int_{t-T_a}^{t} \tilde{P}(t)\; dt \tag{3}$$

and it can change as shown in Figure 4.

Assuming that the supply voltage is sinusoidal and symmetrical, the vector of the load currents:

$$\boldsymbol{i} \triangleq [i_R, i_S, i_T]^T \tag{4}$$

can be decomposed into the fundamental harmonic and distorted currents, namely:

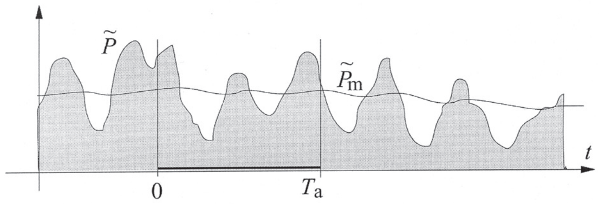

Fig. 4. Plot of the median active power

$$\boldsymbol{i} = \boldsymbol{i}_1 + \boldsymbol{i}_h \tag{5}$$

where the current fundamental harmonic contains the active, reactive and unbalanced currents:

$$\boldsymbol{i}_1 = \boldsymbol{i}_a + \boldsymbol{i}_r + \boldsymbol{i}_u \tag{6}$$

The load equivalent conductance of the FVL can be defined as:

$$\tilde{G}_e \triangleq \frac{\tilde{P}}{||\boldsymbol{u}||^2} \tag{7}$$

where:

$$||\boldsymbol{u}|| \triangleq \sqrt{U_R^2 + U_S^2 + U_T^2} \tag{8}$$

is the supply voltage three-phase rms value. This conductance varies in time like the running active power of the load. The equivalent conductance of the load with the median active power is equal to:

$$\tilde{G}_m \triangleq \frac{\tilde{P}_m}{||\boldsymbol{u}||^2} \tag{9}$$

The load active power can be expressed as:

$$\tilde{P} = \tilde{G}_e ||\boldsymbol{u}||^2 = \tilde{G}_m ||\boldsymbol{u}||^2 + (\tilde{G}_e - \tilde{G}_m)||\boldsymbol{u}||^2 = \tilde{P}_m + \tilde{P}_d \tag{10}$$

where:

$$\tilde{P}_d \triangleq (\tilde{G}_e - \tilde{G}_m)||\boldsymbol{u}||^2 \tag{11}$$

is the *deviation active power.*

Two active currents are associated with these two pow-ers: A *deviation active current:*

$$\boldsymbol{i}_{ad} \triangleq (\tilde{G}_e - \tilde{G}_m)\boldsymbol{u} \tag{12}$$

and a *median active current:*

$$\boldsymbol{i}_{am} \triangleq \tilde{G}_m \boldsymbol{u} \tag{13}$$

where:

$$\boldsymbol{u} \triangleq [u_R, u_S, u_T]^T \tag{14}$$

Thus, the current of time-variant load supplied with sinusoidal symmetrical voltage can be decomposed as follows:

$$\boldsymbol{i} = \boldsymbol{i}_{am} + \boldsymbol{i}_{ad} + \boldsymbol{i}_r + \boldsymbol{i}_u + \boldsymbol{i}_h \tag{15}$$

The median active current $\boldsymbol{i}_{am}$ in this decomposition is just the current that should remain after compensation. Other ones should be entirely compensated or at least, reduced. The deviation active current $\boldsymbol{i}_{ad}$ has to be compensated by the CPV, meaning by the compensator with sufficient energy storage/release capability. Compensation of the harmonic current $\boldsymbol{i}_h$ requires CCD, meaning a PWM-based high frequency switching compensator. The reactive and unbalanced currents, $\boldsymbol{i}_r$ and $\boldsymbol{i}_u$ can be compensated by the CPV, along with the deviation active current $\boldsymbol{i}_{ad}$, or by the CCD, along with the harmonic current $\boldsymbol{i}_h$. However, since high frequency switching is not needed for compensating the reactive and unbalanced currents, it seems reasonable that these currents are compensated by the CPV. This is because the cost of a switching compensator declines with reduction in switching frequency of power semiconductor switches. In such a case, the reference signals for the compensator of the power variation should be proportional to:

$$\boldsymbol{i}_x = \boldsymbol{i}_{ad} + \boldsymbol{i}_r + \boldsymbol{i}_u \tag{16}$$

while the reference signals for the compensator of the current distortion should be proportional to:

$$\boldsymbol{i}_y = \boldsymbol{i}_h \tag{17}$$

These two reference signals have to contain, moreover, a small component proportional to the active current, because of energy dissipation in both compensators.

IV. COMPENSATOR REFERENCE SIGNALS

The components of the reference signal $\boldsymbol{i}_x$ for the CPV control can be calculated based on the analysis of the power properties of the load. Calculation of the reactive and unbalanced currents, $\boldsymbol{i}_r$ and $\boldsymbol{i}_u$, requires analysis of these properties in the observation time-window. Calculation of the deviation active current, $\boldsymbol{i}_{ad}$, requires averaging over interval T_a.

Calculation of the reference signal $\boldsymbol{i}_y$ for the CCD control, according to eqn. (17), would require Fourier analysis of the load current $\boldsymbol{i}$, which would be computationally very demanding. It could be avoided if the harmonic current $\boldsymbol{i}_h$ is calculated from eqn. (5), namely:

$$\boldsymbol{i}_h = \boldsymbol{i} - \boldsymbol{i}_1 \tag{18}$$

Thus, calculation of the reference signal $\boldsymbol{i}_y$ can be reduced to calculation of the fundamental harmonic of the load current.

To identify power properties of the load for generating the reference signal for the compensator control, voltages and currents are sampled with an A/D converter which provides N samples per observation window, stored next in the DSP system. Sampling should be synchronized with the observation window, meaning that the sample k-N should be taken with a fixed time delay with respect to the

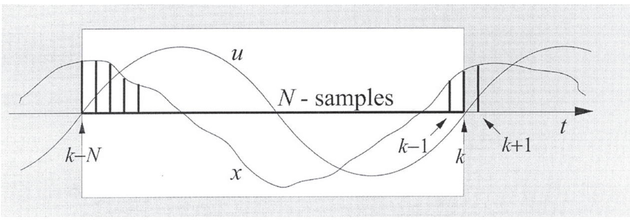

Fig. 5. Sampling in the observation window

voltage positive zero crossing and all samples should be equidistant, taken with the time interval $T_s = T/N$, as shown in Figure 5.

The semi-periodic voltages and current in the observation window can be regarded as the voltages and currents in a single period T of a *periodic extension* of what is observed in this window. Thus, power properties of the load in this single period of the periodic extension can be analyzed and described using the Currents Physical Components power theory. The results of this analysis are valid, however, only in the observation window, but not beyond it. All parameters of the load change with the observation time and therefore, they have to be regarded as running parameters, which is marked with symbol "~".

Two line currents i_R and i_S and two line-to-line voltages u_{RT} and u_{ST} are sampled to provide data on the load power properties. Let us denote them by x and their samples by x_n. The running complex rms (crms) value of the fundamental harmonic of quantity x at the end of the observation window, meaning at the instant $t_k = kT_s$, calculated using the Discrete Fourier Transform (DFT), is equal to:

$$\tilde{\boldsymbol{X}}_{1k} = \frac{\sqrt{2}}{N} \sum_{n=k-N+1}^{n=k} x_n\, e^{-j\frac{2\pi}{N}n} \triangleq \tilde{X}_{1k}\, e^{-j\tilde{\beta}_{1k}} \tag{19}$$

The amount of calculations is reduced if the running crms value is calculated with a recursive formula [7], since:

$$\tilde{\boldsymbol{X}}_{1k} = \frac{\sqrt{2}}{N} \sum_{n=k-N}^{n=k-1} x_n\, e^{-j\frac{2\pi}{N}n} + (x_k - x_{k-N})\frac{\sqrt{2}}{N} e^{-j\frac{2\pi}{N}k} = \tag{20}$$

$$= \tilde{\boldsymbol{X}}_{1k-1} + (x_k - x_{k-N})\frac{\sqrt{2}}{N} e^{-j\frac{2\pi}{N}k}$$

This formula enables the calculation of the running crms value at instant t_k by only updating its value calculated at the instant t_{k-1}. When the k-sample is equal to the sample taken one interval T earlier, and stored in the DSP memory, meaning the (k-N)-sample, the running crms value remains unchanged. Since calculations of crms values and circuit parameters are confined in this paper only to the fundamental harmonic, the index "1" at these values and parameters will be neglected, thus:

$$\tilde{\boldsymbol{X}}_k \triangleq \tilde{\boldsymbol{X}}_{1k}, \quad \omega \triangleq \omega_1 \triangleq \frac{2\pi}{T}$$

When the values of the complex coefficient:

$$\frac{\sqrt{2}}{N} e^{-j\frac{2\pi}{N}k} \tag{21}$$

are stored in the DSP system look-up table, only two multiplications are needed for updating the running crms values of the fundamental harmonic. Thus, only eight multiplications are needed for calculating the running crms values:

$$\tilde{\boldsymbol{I}}_{Rk},\ \tilde{\boldsymbol{I}}_{Sk},\ \tilde{\boldsymbol{U}}_{RTk},\ \tilde{\boldsymbol{U}}_{STk}$$

and for calculating parameters of an equivalent circuit of the load, as shown in Figure 6.

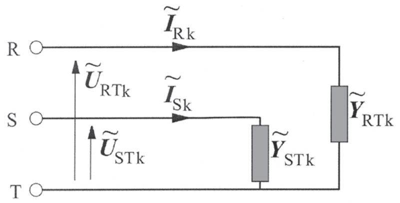

Fig. 6. Equivalent circuit of the load

with:

$$\tilde{\boldsymbol{Y}}_{STk} = \frac{\tilde{\boldsymbol{I}}_{Sk}}{\tilde{\boldsymbol{U}}_{STk}}, \qquad \tilde{\boldsymbol{Y}}_{RTk} = \frac{\tilde{\boldsymbol{I}}_{Rk}}{-\tilde{\boldsymbol{U}}_{RTk}} \tag{22}$$

The running equivalent admittance of the load, needed for calculating the active and reactive currents, is:

$$\tilde{Y}_{ek} \triangleq \tilde{G}_{ek} + j\tilde{B}_{ek} = \tilde{\boldsymbol{Y}}_{STk} + \tilde{\boldsymbol{Y}}_{TRk} = \frac{\tilde{\boldsymbol{I}}_{Sk}}{\tilde{\boldsymbol{U}}_{STk}} - \frac{\tilde{\boldsymbol{I}}_{Rk}}{\tilde{\boldsymbol{U}}_{TRk}} \tag{23}$$

and the running unbalanced admittance of the load, needed for calculating the unbalanced current, is:

$$\tilde{\boldsymbol{A}}_k \triangleq -(\tilde{\boldsymbol{Y}}_{STk} + \alpha\tilde{\boldsymbol{Y}}_{TRk}) = -(\frac{\tilde{\boldsymbol{I}}_{Sk}}{\tilde{\boldsymbol{U}}_{STk}} - \alpha\frac{\tilde{\boldsymbol{I}}_{Rk}}{\tilde{\boldsymbol{U}}_{TRk}}),\ \ \alpha \triangleq 1e^{j120^0} \tag{24}$$

Since the vector of the running crms values of the line-to-ground voltages at symmetrical supply is equal to:

$$\tilde{\mathbf{U}}_k \triangleq \begin{bmatrix} \tilde{\boldsymbol{U}}_R \\ \tilde{\boldsymbol{U}}_S \\ \tilde{\boldsymbol{U}}_T \end{bmatrix}_k = \frac{1}{\sqrt{3}} \begin{bmatrix} \tilde{\boldsymbol{U}}_{RT}\, e^{j30^0} \\ \tilde{\boldsymbol{U}}_{ST}\, e^{-j30^0} \\ \tilde{\boldsymbol{U}}_{ST}\, e^{j150^0} \end{bmatrix}_k \tag{25}$$

then, the values of the active, reactive and unbalanced currents at the instant t_k are:

$$\boldsymbol{i}_{ak} = \sqrt{2}\,\mathrm{Re}\{\tilde{G}_{ek}\tilde{\mathbf{U}}_k\, e^{j\omega t_k}\} \tag{26}$$

$$\boldsymbol{i}_{rk} = \sqrt{2}\,\mathrm{Re}\{j\tilde{B}_{ek}\tilde{\mathbf{U}}_k\, e^{j\omega t_k}\} \tag{27}$$

$$\boldsymbol{i}_{uk} = \sqrt{2}\,\mathrm{Re}\{\tilde{A}_k\tilde{\mathbf{U}}_k^{\#}\, e^{j\omega t_k}\} \tag{28}$$

where $\tilde{\mathbf{U}}_k^{\#}$ denotes vector $\tilde{\mathbf{U}}_k$ with switched elements $\tilde{U}_{\rm S}$ and $\tilde{U}_{\rm T}$.

The equivalent conductance, averaged over interval $T_{\rm a}$, provides a median value of this conductance and hence, the deviation active current at the instant t_k is:

$$\boldsymbol{i}_{{\rm ad}k} = \sqrt{2}\,{\rm Re}\{(\tilde{G}_{{\rm e}k} - \tilde{G}_{{\rm m}k})\tilde{\mathbf{U}}_k\, e^{j\omega t_k}\} \tag{29}$$

and the reference signal at the instant t_k for the CPV compensator should be equal to:

$$\begin{aligned} \boldsymbol{i}_{{\rm x}k} &= \boldsymbol{i}_{{\rm ad}k} + \boldsymbol{i}_{{\rm r}k} + \boldsymbol{i}_{{\rm u}k} = \\ &= \sqrt{2}\,{\rm Re}\Big\{[(\tilde{G}_{{\rm e}k} - \tilde{G}_{{\rm m}k}) + j\tilde{B}_{{\rm e}k}]\tilde{\mathbf{U}}_k + \tilde{A}_k\tilde{\mathbf{U}}_k^{\#}\, e^{j\omega t_k}\Big\} = \\ &= \sqrt{2}\,{\rm Re}\Big\{\Big[\tilde{C}_k\tilde{\mathbf{U}}_k + \tilde{A}_k\tilde{\mathbf{U}}_k^{\#}\Big]e^{j\omega t_k}\Big\} \end{aligned} \tag{30}$$

with:

$$\tilde{C}_k \triangleq (\tilde{G}_{{\rm e}k} - \tilde{G}_{{\rm m}k}) + j\tilde{B}_{{\rm e}k} \tag{31}$$

The reference signal at the instant t_k for the CCD compensator control should be equal to:

$$\begin{aligned} \boldsymbol{i}_{{\rm y}k} &= \boldsymbol{i}_k - \boldsymbol{i}_{1k} = \boldsymbol{i}_k - (\boldsymbol{i}_{{\rm a}k} + \boldsymbol{i}_{{\rm r}k} + \boldsymbol{i}_{{\rm u}k}) = \\ &= \boldsymbol{i}_k - \sqrt{2}\,{\rm Re}\{[(\tilde{Y}_{{\rm e}k}\tilde{\mathbf{U}}_k + \tilde{A}_k\tilde{\mathbf{U}}_k^{\#}]e^{j\omega t_k}\} \end{aligned} \tag{32}$$

Observe that the reference signal, $\boldsymbol{i}_{{\rm x}k}$, for the CPV is entirely calculated, while the signal $\boldsymbol{i}_{{\rm y}k}$ for the CCD is a difference of the measured and calculated currents.

V. REFERENCE SIGNALS PREDICTION

Using data on voltages and currents stored in the DSP memory and their samples acquired at the instant t_k, the DSP System can identify power properties of the load, meaning the physical components of the load currents. If the assumptions made in this paper are valid, then the load has these properties in the window of observation, including the instant t_k. However, based on these current values, reference signals would be created for the compensators control and compensators would reproduce these signals as their output currents. These currents would be injected into the supply lines of the load with a delay, at the instant of time when all harmful components of the load current would have different values. Therefore, prediction of the load properties, meaning the values of harmful current components at the instant of their injection is necessary for the compensators proper control.

It can be assumed that compensating currents are injected into the system with the delay equal to the sampling interval, $T_{\rm s}$, meaning at the instant t_{k+1}.

Prediction of values of the load current components at the instant $t_{k+1} = t_k + T_{\rm s}$, meaning at the instant $T_{\rm s}$ beyond the observation window, is equivalent to predicting these these values at the instant t_k in the new window, shifted by $T_{\rm s}$, or in the original window, where all quantities, denoted by x', were shifted back by $T_{\rm s}$. Thus, in the original window:

$$x'(t) = x(t + T_{\rm s}) \tag{33}$$

therefore, the running crms value of the fundamental harmonic of such quantity is:

$$\tilde{X}' = \tilde{X}'\, e^{j\omega T_{\rm s}} \tag{34}$$

Thus, the reference signal for the CVD should be proportional to:

$$\boldsymbol{i}_{{\rm x}k+1} \triangleq \boldsymbol{i}'_{{\rm x}\,k} = \sqrt{2}\,{\rm Re}\{[\tilde{C}'_k\tilde{\mathbf{U}}_k + \tilde{A}'_k\tilde{\mathbf{U}}_k^{\#}]e^{j\omega t_k}\} \tag{35}$$

where complex coefficients $\tilde{C}'_k$ and $\tilde{A}'_k$ can be calculated by a linear approximation, namely:

$$\tilde{C}'_k \triangleq \tilde{C}_{k+1} = \tilde{C}_k + (\tilde{C}_k - \tilde{C}_{k-1}) = 2\tilde{C}_k - \tilde{C}_{k-1} \tag{36}$$

$$\tilde{A}'_k \triangleq \tilde{A}_{k+1} = \tilde{A}_k + (\tilde{A}_k - \tilde{A}_{k-1}) = 2\tilde{A}_k - \tilde{A}_{k-1} \tag{37}$$

The reference signal for the CCD can be predicted in a similar way, namely:

$$\boldsymbol{i}_{{\rm y}k+1} \triangleq \boldsymbol{i}'_{{\rm y}k} = \boldsymbol{i}'_k - \sqrt{2}\,{\rm Re}\{[\tilde{C}'_k\tilde{\mathbf{U}}_k + \tilde{A}'_k\tilde{\mathbf{U}}_k^{\#}]e^{j\omega t_k}\} \tag{38}$$

with:

$$\boldsymbol{i}'_k \triangleq \boldsymbol{i}_{k+1} = \boldsymbol{i}_k + (\boldsymbol{i}_k - \boldsymbol{i}_{k-1}) = 2\boldsymbol{i}_k - \boldsymbol{i}_{k-1} \tag{39}$$

The complex coefficients $\tilde{C}_{k+1}$ and $\tilde{A}_{k+1}$ can be predictted with high accuracy, because the values of $\tilde{C}_k$, $\tilde{C}_{k-1}$, $\tilde{A}_k$ and $\tilde{A}_{k-1}$ are obtained in effect of observing the load properties in N instants of time, over entire observation window, thus they do not change abruptly. This cannot be said, however, on prediction of the current value $\boldsymbol{i}_{{\rm x}k+1}$. The prediction error can be reduced only by an increase in the sampling rate.

VI. CONCLUSIONS

The presented method of generating the reference signals for hybrid compensator control integrates the frequency-domain approach to identification of power properties of three-phase unbalanced, time-variant loads within the time-domain. The reference signals are calculated almost instantaneously, after the set of voltage and current samples is provided at the instant t_k. However, this calculation takes into account a short-term "history" of the load properties in the observation time-window of T duration, determined with the set of samples stored in the DSP system memory. It also takes into account a long-term "history" in the process of averaging the load active power over averaging time $T_{\rm a}$. Therefore, generation of the reference signals for the compensator control is only apparently "instantaneous." It is "instantaneous" in the sense, that the signals are generated directly after the single set of samples is provided by the data acquisition system, with only a small delay needed for calculation, but a the same time, the "history" of the load properties is included into these signals. Therefore, the adverb "quasi-instantaneous" was used in this paper for this kind of reference signal generation.

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