A SIMPLIFIED HANDLE SCHEME IN DG SYSTEM FOR DUAL-INTERFACING CONVERTERS

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ABSTRACT-It is analyzed in this paper that the compensation of local load harmonic current using a single DG interfacing converter may cause the amplification of supply voltage harmonics to sensitive loads, particularly when the main grid voltage is highly distorted. In this paper a new scheme is introduced for the simultaneous microgrid voltage and current harmonic compensation using coordinated control of Dual-Interfacing converters. Specifically, the first converter is responsible for local load supply voltage harmonic suppression. The second converter is used to mitigate the harmonic current produced by the interaction between the first interfacing converter and the local nonlinear load. To realize a simple control of parallel converters, a modified hybrid voltage and current controller is also developed in the paper. By using this proposed controller, the grid voltage phase-locked loop and the detection of the load current and the supply voltage harmonics are unnecessary for both interfacing converters. Thus, the computational load of interfacing converters can be significantly reduced. Space Vector Modulation (SVM) Technique has become the important PWM technique for three phase Voltage Source Inverters by utilizing the DC bus voltage more efficiently and generates less harmonic distortion when compared with Sinusoidal PWM (SPWM) technique. Simulated results are captured to validate the performance of the proposed topology and the control strategy.

Index Terms—Active power filter (APF), dynamic voltage re storer (DVR), harmonic detection, LCL filter, parallel converters, phase-locked loop, power quality, resonance SVPWM controller.

I INTRODUCTION

The exponential growth in nonlinear loads has generated a prime concern in the power supply systems. Power electronics based applications draw non-sinusoidal currents, although the applied voltage being sinusoidal. Because of the non-ideal characteristics of voltage source, harmonic currents create voltage distortion. Various nonlinear loads such as arc furnaces, cycloconverters, rectifiers, variable speed drives and other asymmetrical loads can cause huge disturbances in the power supply system. In order to retain harmonic disturbances at reasonable levels, to comply with present standards, we can go through various solutions applicable to supply systems and to harmonics sources.

Conventional solutions like passive filters (PF) for mitigating the harmonic pollution are ineffective due to fixed compensation, large size, and resonance [1]. With the enormous growth of power electronics and applications, design and development of Active Power Filter (APF) to improve the power quality has been the focus of many papers presented in literature. In recent times, various publications have appeared on the harmonics, reactive power, load balancing, and neutral current compensation related with linear and nonlinear loads.

The development of control algorithm which influences the rating, the steady state and the dynamic performance constitutes the core part of the APF. Different control algorithms have been reported in the literature such as proportional integral (PI) control, dead-beat control, and hysteresis control [8]. Due to the restriction of the control bandwidth, the PI controller is not an appropriate solution for the APF applications as the current controller should deal with harmonic currents, which are high frequency signals. In contrast, the dead-beat controller is capable of giving fast control response, but the control performance depends extensively on knowledge of the APF parameters. In spite of the simple and robust feature of the hysteresis control, this method also has an intrinsic drawback of switching frequency variation, which causes a difficulty in design of ripple filter for the APF and results in redundant resonance problems with the system. Additionally, in order to attain superior current control, the hysteresis band limit has to be set as small as possible. It results in a major increase of the switching frequency and as a result introduces huge switching loss on the APF. In order to overcome the deficiencies of the above mentioned control methods, various modern current control techniques have been developed.

Numerous applications of SVPWM control were reported earlier in VSI fed induction motor drives. In recent times, the SVPWM technique is also gaining importance in APF control. However, the computational burden involved due to complex trigonometric calculations and sector identification
limits the application of SVPWM technique for APF application. An improved SVPWM technique with “effective time concept” has been developed to overcome the above drawback in induction motor drive applications. This effective time concept in the improved SVPWM technique is able to overcome the disadvantages of complex trigonometric calculations and sector identification and it finds a useful application in APF control.

Nevertheless, it is important to emphasize that even when the local load harmonic current is properly compensated using various controllers as mentioned above, high-quality supply voltage to local load cannot be guaranteed at the same time.

Unfortunately, the functionality of a DVR can hardly be implemented in a shunt DG interfacing converter. Using an additional series power conditioning equipment to ensure very low steady-state harmonic supply voltage to local loads is definitely feasible. However, it is associated with more expenses which might not be accepted for cost-effective power distribution systems. To realize simultaneous mitigation of the grid current and the supply voltage harmonics, this paper develops a parallel converter topology where the local nonlinear load is directly installed to the shunt filter capacitor of the first converter. The local load supply voltage quality is enhanced by the first interfacing converter through harmonic voltage control. To reduce the computational load of the dual-converter system, a modified hybrid voltage and current control method is proposed for parallel interfacing converters. With cooperative operation of two converters, the load current and supply voltage harmonic extraction and the phase-locked loops are not needed to realize this proposed comprehensive power quality control objective. Note that this paper focuses on the compensation of supply voltage and grid current harmonics.

II REVIEW OF CONVENTIONAL APF AND DVR

This section briefly reviews the control of shunt APFs for grid current harmonic mitigation and series DVRs for supply voltage harmonic suppression. In order to compare with the proposed parallel converter using modified hybrid voltage and current controller as shown in the next section, the well-understood double-loop current control and voltage control are applied to APFs and DVRs, respectively.

A. Shunt Interfacing Converters for Grid Current Harmonic Mitigation

Fig. 1(a) shows the topology and control strategy of an interfacing converter for compensating harmonic current from a local nonlinear load. First, the local load is connected to the output of the interfacing converter, and then, they are coupled to the main grid through the grid feeder. The parameters of the interfacing converter LCL filter and the grid feeder are listed as $z_1(s) = sL_1 + R_1$, $z_2(s) = sL_2 + R_2$, $z_3(s) = 1/(sC_f)$, and $z_g(s) = sL_g + R_g$, where $L_1$, $L_2$, $R_1$, and $R_2$ are the inductance and resistance of the filter series chokes, $C_f$ is the capacitance of the shunt capacitor, and $L_g$ and $R_g$ are grid inductance and resistance. The current control scheme is shown in the lower part of Fig. 1(a). According to the traditional APF control theory, the local load current is measured and the harmonic components are detected as

$$I_{L2,ref,h} = H_{Har}(s) \cdot I_{Load}$$  \hspace{1cm} (1)

Where $H_{Har}(s)$ is the transfer function of the harmonic component detector and $I_{Load}$ is the local load current. When both the fundamental and the harmonic components are determined, the reference current is obtained as $I_{2,ref} = I_{2,ref,f} + I_{2,ref,h}$ and it is used as the input for a double-loop line current $I_2$ control [27] as

$$I_{2,ref} = H_{Outer}(s) \cdot (I_{2,ref,f} - I_2)$$  \hspace{1cm} (2)

$$V_{out,ref} = H_{Inner}(s) \cdot (I_{2,ref} - I_1)$$  \hspace{1cm} (3)

Where $H_{Outer}(s)$ and $H_{Inner}(s)$ are the regulators of the outer and the inner control loops, respectively. $I_{1,ref}$ and $I_1$ are the reference and the instantaneous inverter output current, respectively. $V_{out,ref}$ is the output voltage reference of the inverter.

B. Series Interfacing Converters for Supply Voltage Harmonic Mitigation

It is important to note that even when the harmonic current of shunt nonlinear loads is compensated, the supply voltage to local load is not always purely sinusoidal. This can be caused by a few reasons including the main grid voltage steady-state harmonic distortions. Suppose the grid current $I_g$ in Fig. 1(a) is ripple free, the harmonic voltage drop on the grid feeder $R_g$ and $L_g$ is zero. In this case, the harmonic voltage at PCC is the same as the harmonics from the main grid. To address the aforementioned problem, a series DVR can be installed as shown in Fig. 1(b), where the system is coupled with the power distribution network using a series-connected matching transformer.
The secondary of the transformer is connected to a converter with output LC filter. First, the PCC voltage is measured by the DVR controller and the fundamental and harmonic PCC voltage components are separated. Then, the supply voltage harmonic components are compensated by setting up the harmonic voltage reference of the DVR as $V_{\text{ref, h}} = V_{\text{PCC, h}}$ [35] and the fundamental voltage reference $V_{\text{ref, f}}$ of the DVR is determined according to the sag and swell compensation requirement of the system [3]. When the fundamental and harmonic component references are determined, the DVR reference voltage is obtained as $V_{\text{C, ref}} = V_{\text{C, ref, f}} + V_{\text{C, ref, h}}$. Afterward, a double-loop voltage control is applied to ensure a rapid voltage tracking as

$$I_{\text{ref}} = H_{\text{outer}}(s). (V_{\text{C, ref}} - V_C) \quad (4)$$

$$V_{\text{out, ref}} = H_{\text{inner}}(s). (I_{\text{ref}} - I_1) \quad (5)$$

Where $H_{\text{outer}}(s)$ and $H_{\text{inner}}(s)$ are the regulator of the outer and the inner control loops, respectively. $V_{\text{C, ref}}$ and $V_C$ are the reference and the instantaneous value of DVR voltage, respectively.

III. PROPOSED COORDINATED CONTROL METHOD

To have simultaneous mitigation of the supply voltage and the grid current harmonics, a compensation method using coordinated control of two parallel interfacing converters is proposed in this section. The circuitry and control diagrams of the proposed system are shown in Figs. 2 and 3, respectively. First, a DG unit with two parallel interfacing converters sharing the same dc rail is connected to PCC. Each interfacing converter has
an output LCL filter and the local nonlinear load is placed at the output filter capacitor of converter1. In this topology, the supply voltage to local nonlinear load is enhanced by controlling the harmonic component of interfacing converter1. Meanwhile, the grid current harmonic is mitigated via the power conditioning through interfacing converter2. Their detailed control strategies are discussed, respectively, as shown below.

**Fig.4. Phasor diagram of converter1 line current**

**A. Control Strategy for Converter1**

First, the line current $I_{2,C1}$ of converter1 and the PCC voltage $V_{PCC}$ as shown in Fig. 2 are measured to calculate the real and reactive output power of this converter

\[
\begin{align*}
    P_{c1} &= \frac{3T}{2(S + T)}(V_{PCC,a}I_{2a,C1} + V_{PCC,b}I_{2b,C1}) \\
    Q_{c1} &= \frac{3T}{2(S + T)}(V_{PCC,b}I_{2a,C1} - V_{PCC,a}I_{2b,C1})
\end{align*}
\]

(6)

where $P_{c1}$ and $Q_{c1}$ are the output real and reactive power of converter1, $V_{PCC,a}$ and $V_{PCC,b}$ are the PCC voltage in the two-axis stationary reference frame, and $I_{2a,C1}$ and $I_{2b,C1}$ are the line current of converter1, and $\tau$ is the time constant of low-pass filters. The time constant of the low-pass filter is mainly determined by two factors. First, the real and reactive power ripples caused by line current harmonics must be properly filtered out. Second, the rapid dynamic power control shall be maintained. According to the design guideline in [39], the $\tau$ is selected to be 6.28 in this paper.

It is important to note that the power reference is usually determined according to the available power from the back stage of the DG unit. When there is energy storage system in the DG unit, the power reference can also be determined by the energy management system of a DG unit or a microgrid. Therefore, for the sake of simplicity, the harmonic compensation service is usually activated when there is sufficient power rating in the interfacing converters [13] and [14]. The output of the power reference generator is the line current reference $I^*_{2,PQ,C1}$ as

\[
I^*_{2,PQ,C1} = g_p(V_{PCC,a} + jV_{PCC,b}) + g_q(V_{PCC,b} - jV_{PCC,a})
\]

(7)

Where $g_p$ and $g_q$ are two adjustable gains that can regulate converter1 output real and reactive power, respectively. This controller simply uses a copy of the instantaneous PCC voltage vector ($V_{PCC,a} + jV_{PCC,b}$) and the conjugated component as the current reference. This is based on a fact that the real output power is in proportion to the line current $I_2$ that aliens to instantaneous PCC voltage vector, while the reactive power is proportional to the line current that aliens to the conjugated PCC vector $V_{PCC,b} - jV_{PCC,a}$, as shown in Fig. 4. The gains $g_p$ and $g_q$ in (7) are determined by two PI regulators as

\[
\begin{align*}
    g_p &= \left( k_{p,pq} + \frac{k_{pq}}{s} \right)(P_{ref} - P_{c1}) \\
    g_q &= \left( k_{p,pq} + \frac{k_{pq}}{s} \right)(Q_{ref} - Q_{c1})
\end{align*}
\]

(8)

Where $k_{p,pq}$ and $k_{pq}$ are PI controller coefficients. $P_{ref}$ and $Q_{ref}$ are the reference real and reactive power, respectively. Traditionally, the hybrid regulator in [27] controls the DG fundamental voltage for power control and the harmonic current for load harmonic current mitigation. As this converter is responsible for compensating harmonic components of the supply voltage, the regulators in the hybrid voltage and current controller is modified with harmonic supply voltage control and fundamental line current control as

\[
\begin{align*}
    V_{out,C1}^* &= power control \\
    &+ voltage harmonic mitigation \\
    &+ Active damping
\end{align*}
\]

(9)

where $V_{out,C1}^*$ is the reference voltage for PWM processing, $I^*_{2,PQ,C1}$ is the line current reference of the power control term, $V^*_{C,C1}$ is the reference voltage of the voltage harmonic mitigation term, $V_{C,C1}$ is the filter capacitor voltage, and $I_{1,C1}$ is the converter1 output current. As shown in Fig.2, the filter capacitor voltage ($V_{C,C1}$) is the same as the load voltage ($V_{supply}$). The regulators of the power control, voltage harmonic mitigation, and active damping terms are listed as

\[
H_{pq}(s) = k_{p1,c1} + \frac{2k_{1f,ctw_{0}5}}{s^2 + 2aw_{0}5 + (h_{0})^2}
\]

(10)

\[
H_{har}(s) = k_{p2,c1} + \sum_{h=5,7,11,13} \frac{2k_{1f,ctw_{0}5}}{s^2 + 2aw_{0}5 + (h_{0})^2}
\]

(11)

\[
H_{ad}(s) = k_{ad,c1}
\]

(12)

where $k_{pq,c1}$ is the proportional gain and $k_{1f,ctw_{0}5}$ is the resonant controller gain for the power control regulator $H_{pq}(s)$, $k_{p2,c1}$ is the proportional gain and $k_{1f,ctw_{0}5}$ is the resonant controller gain for the voltage harmonic mitigation regulator $H_{har}(s)$, and $k_{ad,c1}$ is the proportional control that can actively suppress the LCL filter resonance. It is necessary to note that only the fundamental proportional gains
kp1,C1 and kp2,C1 is much lower than the resonant controller gain kv,h,C1. As a result, the output of the power control term in (9) has very low-harmonic component. Due to this feature, the distorted grid voltage can be directly used as the input of (7), as its harmonic component can be automatically filtered out by (10). At the same time, it can be seen that the output of the second voltage harmonic mitigation term only has very low fundamental components, as only resonant controllers at the selected harmonic frequencies are adopted in the control term. Thus, the power control term and voltage harmonic mitigation term are very well decoupled. Accordingly, an interfacing converter can dispatch power to the grid and compensate supply voltage harmonics at the same time. In addition, unlike the conventional DVR with PCC harmonic voltage extractions, the voltage harmonic mitigation term can realize active supply voltage harmonics compensation without any harmonic extractions. In addition, it can be seen that a closed-loop power control is realized without using phase-locked-loops. Finally, it is necessary to emphasize that comparing to the traditional hybrid controller that uses the droop control to realize relatively slow power control dynamics, the fundamental current control in (9) could effectively improve the power control dynamic response.

B. Control Strategy for Converter2

The control strategy of converter2 is similar to that of converter1, as also demonstrated in Fig. 3. However, both the fundamental and the harmonic converter currents are controlled. First, the regulators as shown in (6) to (8) are adopted to obtain the power control term reference I1∗,PQ,C2 for converter2. Afterward, another hybrid controller is used to realize the closed-loop line current control of converter2 as

\[
V_{out2,C2} = P_{power control} + \frac{V_{harmonic mitigation}}{J_{harmonic,C2}} + J_{active damping,C2} (13)
\]

Where \(V_{out,2}\) is the reference voltage for converter2 PWM processing \(I_{2,PQ,C2}\) is the current reference for converter2 power control, \(J_{2,Har,C2}\) is the current reference for converter2 line current harmonic control, and \(I_{1,C2}\) is the converter2 output current. The regulators of power control, current harmonic mitigation, and active damping terms are listed here as

\[
H_{pq}(s) = k_{pq} + \frac{2k_{i,f,C2}s}{s^2 + 2z_{0} + \omega_0 s + \omega_0^2}
\]

\[
H_{har}(s) = k_{pq} + \sum_{n=5,7,11,13} \frac{2k_{i,f,C2}s}{s^2 + 2z_{0} + \omega_0 s + \omega_0^2}
\]

\[
H_{ad}(s) = k_{ad,c2}
\]

Similar to the converter1, the power control term and the current harmonic mitigation term are very well decoupled. Thus, PLLs is not necessary and the input of power control term \(I_{2,PQ,C2}\) can have some distortions when using a direct copy of PCC voltage. In addition, it is important to note that the difference between the converter1 line current and the load current \(I_{load}\) (seen in Fig. 2, equals to \(I_{load} - I_{Load}\)) is adopted as the input of current harmonic mitigation term of converter2 as \(I_{2,Har,C2} = I_{inj}\).

As only harmonic resonant controllers are used in the current harmonic mitigation term and the proportional gain \(k_{pq,C2}\) is much smaller than \(k_{i,h,C2}\) in (15), converter2 can actively compensate the harmonic current from converter1 without any harmonic current detection. In this case, the injected current \(I_{inj}\) to the main grid is harmonic free. In summary, the proposed topology and the modified hybrid controller can realize an enhanced quality of supply voltage to the local load and the grid current to the main grid at the same time. Through the coordinated control of two parallel converters, the aforementioned power quality improvement objective is realized in a computationally effective manner, without involving any PLLs and harmonic voltage/current extractions in the entire process. In addition, when the fundamental current regulation in the power control term in (13) and (9) is replaced by the well understood droop control for fundamental voltage regulation [27], the proposed method can be used in an islanded microgrid in a similar manner.

\[
I_1 + L_2 R_2 + I_{inj} = V_{out} - V_{c}
\]

Fig. 5. Diagram of an LCL filter with a local nonlinear load.

C. Frequency-Domain Analysis

As both converter1 and converter2 have frequency selective feature at the fundamental and the selected harmonic frequencies, the supply voltage harmonic and grid current harmonic compensation performance can be examined by frequency domain analysis using Bode plots. First, an LCL filter of a converter is shown in Fig. 5, where the local load is simplified as a harmonic current source connected to the shunt capacitor of converter LCL filter. The response of the filter plant is given as

\[
V_{out} + V_{pcc} - I_{load} \left(\frac{1}{z_1} + \frac{1}{z_2} + \frac{1}{z_3}\right) = V_c
\]

\[
V_{out} - V_c = z_1, I_1
\]

\[
V_c - V_{pcc} = z_2, I_2
\]

Based on the control strategies in (9) and (13), the transfer function of the LCL filter circuit (see (17) to
(19)) for both converter1 and converter2, and assuming that $V_{out,c2} = V_{out,c1}$ and $V_{out,c1} = V_{out,c1}$, the closed-loop current and voltage response of parallel converters can be established as

$$V_{c1} = R_{11}(s) V_{c1}' + R_{12}(s) i_{p,q,c1}$$

$$i_{c1} = R_{21}(s) i_{c1}' + R_{22}(s) i_{p,q,c1} + R_{3}(s) V_{PCC}$$

(20)

$$i_{c2} = R_{31}(s) i_{p,q,c2} + R_{32}(s) i_{2,har,c2} + R_{3}(s) V_{PCC}$$

(21)

Where the coefficients $R_{11}(s)$ to $R_{31}(s)$ in (20) and (22) describe the response of these two converters to various excitations of the system. Specifically, (20) mainly focuses the performance of converter1 at harmonic frequencies, while (21) aims to describe the performance of the system at around fundamental frequency. In other words, converter1 has voltage source characteristic at harmonic frequencies but current source characteristic at around the fundamental frequency. On the other hand, as both fundamental and harmonic line current are controlled for converter2, only a single current source equivalent circuit in (22) can be used to demonstrate the performance of converter2. In order to make the discussion more straightforward, a complex circuit network as shown in Fig. 6 is developed to show how the harmonic voltage and current harmonic are simultaneously compensated. Note that this equivalent circuit network in Fig. 6 is only effective at the selected harmonic frequencies.

![Fig.6 Equivalent circuit of the proposed method at selected harmonic frequencies.](image)

**IV SPACE VECTOR PULSE WIDTH MODULATION**

Space vector pulse width modulation method is best among all the PWM techniques for drive applications and the three phase voltage source inverters (VSI). Compared to sinusoidal pulse width modulation Method (SPWM), SVPWM has many advantages, which are less switching losses, less total harmonic distortion, it is easy to digitalize and better utilization of dc-bus voltage. The performance of the SVPWM inverter is based on the following criteria: switching losses of the inverter, total harmonic distortion (THD) and maximum output voltage. Originally the SVPWM method is developed as a vector approach to pulse width modulation (PWM) for three phase inverters. In SVPWM inverter the reference wave is revolving reference voltage vector and the carrier signal is high frequency triangular or saw tooth waveform. The intersection of these two will give the gate pulses to inverter to control the voltage and frequency of the inverter.

The SVPWM is better than the other PWM methods due to the following features.

- It has the wide linear modulation range including with PWM third harmonic injection automatically.
- It has lesser switching losses because only one switch is operating at a time in the SVPWM inverter.
- It gives 15.5% more utilization of DC-Link voltage than the conventional PWM methods.
- It has higher efficiency.
- It gives output phase voltage is $V_{ac}/\sqrt{3}$ and output line voltage is $V_{dc}$ , but in SPWM the output phase voltage is $dc/2V$ , output line voltage is $3V_{ac}/\sqrt{2}$ , therefore SVPWM gives more output phase and line voltages than the SPWM inverter.
- It is a digital modulating technique.

The space vector concept is derived from rotating magnetic field theory of three phase induction motor which is used for modulating the inverter output voltage. In this method three phase voltages are transformed to two phase voltages either in stationary reference frame or synchronous rotating reference frame. Using this two phase voltage reference components the inverter output can be modulated. Let us take the three phase balanced voltages as shown below,

$$V_{a} = V_{n}\sin\alpha$$

$$V_{b} = V_{n}\sin(\omega t - \frac{2\pi}{3})$$

$$V_{c} = V_{n}\sin(\omega t + \frac{2\pi}{3})$$

(23)

(24)

(25)

If we apply these three phase balanced voltages to the three phase induction motor. This rotating flux vector magnitude and angle can be calculated using the Clark’s transformation method in stationary reference frame as shown below.

$$\overrightarrow{V_{ref}} = \overrightarrow{V_{a} + jV_{b}} = \frac{2}{3}(V_{a} + V_{b}e^{j2\pi/3} + V_{c}e^{j4\pi/3})$$

(26)

Where $|V_{ref}| = \sqrt{(V_{a}^2 + V_{b}^2)}$ and $\alpha = \tan^{-1}\frac{V_{b}}{V_{a}}$

The above equation is separated into real and imaginary parts which are

$$V_{a} = \frac{2}{3}(V_{a}\cos0 + V_{b}\cos\frac{2\pi}{3} + V_{c}\cos\frac{4\pi}{3})$$

(27)

$$V_{a} = \frac{2}{3}(V_{a}\sin0 + V_{b}\sin\frac{2\pi}{3} + V_{c}\sin\frac{4\pi}{3})$$

(28)
The above equations can be represented in matrix form as shown below

\[
\begin{bmatrix}
V_r \\
V_\beta
\end{bmatrix}
= \begin{bmatrix}
1 & -1 & -1 \\
0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2}
\end{bmatrix}
\begin{bmatrix}
V_{gs} \\
V_{gs} \\
V_{cs}
\end{bmatrix}
\]

(29)

Fig: 7 Representation of rotating vector in complex plane

V SIMULATION RESULTS

Simulated results are obtained to further verify the performance of the proposed controller for coordinated operation of parallel converters. First, similar to Fig. 1, a single interfacing converter is connected to the main grid and the local nonlinear load is placed at the output terminal of the DG unit.

When the current controller is applied to the system, the performance of the system is shown in Figs. 8.

Fig. 8. Only the local load harmonic current is compensated. (From upper to lower: V supply, Ig, I2, ILoad).

When the supply voltage harmonic component is controlled by a single interfacing converter using the hybrid voltage and current control as shown in (9), the performance is shown in Fig. 9.

Fig. 9. Only the supply voltage harmonic component is compensated. (From upper to lower: V supply, Ig, I2, ILoad).

The simulated results are shown from Figs. 10 to 13. First, the main grid voltage and the grid current are shown in Fig. 10.

Fig. 10. Main grid voltage and the grid current when the proposed coordinated control is applied. (From upper to lower: Vg, Ig).

The performance of converter1 is shown in Fig. 11. As this converter is applied to compensate the harmonics in the supply voltage, it can be seen that the voltage waveform in the top of the figure is almost ripple-free. However, the line current of this converter is distorted. In addition, the performance of converter2 is shown in Fig. 12.

Fig. 11. Performance of converter1. (From upper to lower: Vsupply, I2, C1, inj, Iload).

Fig. 12. Performance of converter2. (From upper to lower: Vc, C2, I2, C2, I2, Har, C2).
The objective of this control strategy has been verified as the grid current is sinusoidal in the second channel of Fig. 17.

Fig. 13 that both converters have a rapid response to PQ reference change. There is no obvious overshoot during this process and the steady-state power control error is zero. To fully verify the performance of the proposed method, a simulation is conducted where a highly distorted grid voltage with 10% THD is used, as shown in the top of Fig. 14.

Fig. 13. Real and reactive power of converter 1 and converter 2

Fig. 14. Performance of the dual-converter system during 10% grid voltage sags, with 10.03% THD.

VI CONCLUSION

This paper discusses a novel coordinated voltage and current controller for dual-converter system in which the local load is directly connected to the shunt capacitor of the first converter. When a single multifunctional interfacing converter is adopted to compensate the harmonic current from local non-linear loads, the quality of supply voltage to local load can hardly be improved at the same time, particular when the main grid voltage is distorted. With the dual-interfacing converters configuration, the quality of supply voltage can be enhanced via a direct closed-loop harmonic voltage control of filter capacitor voltage. At the same time, the harmonic current caused by the nonlinear load and the first converter is compensated by the second converter by using SVPWM controller. Thus, the quality of the grid current and the supply voltage are both significantly improved. To reduce the computational load of DG interfacing converter, the coordinated voltage and current control without using load current/supply voltage harmonic extractions or phase-lock loops is developed to realize to coordinated control of parallel converters. It is necessary to note that the proposed method is focused on compensating the harmonics in a microgrid system or a power distribution system.

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